SkySync:
A Personal Weather Station

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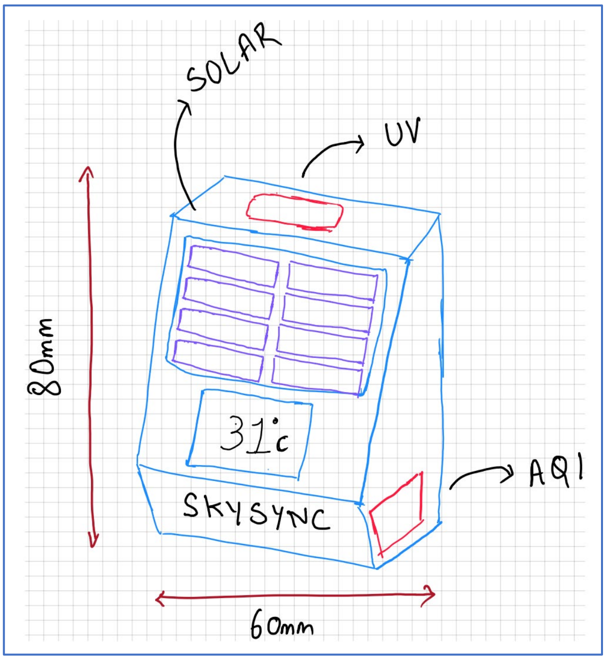
In today's rapidly evolving data-centric ecosystem, data isn't just pivotal – it's transformational. Our ability to make informed decisions, whether in our personal lives or professional domains, largely rests on the accuracy and timeliness of the data we collect. Enter SkySync, a personal weather station tailored for the modern user. Unlike traditional weather stations which are fixed and bulky, SkySync is portable, user-friendly, and designed to seamlessly integrate with your daily activities.



1: Napkin Sketch of how it might look.

Unique Value Propositions

- **On-the-Go Environmental Intelligence**: Whether you're an outdoor enthusiast embarking on a hike or a biker embracing the wilderness, SkySync can be effortlessly attached to your backpack, ensuring that you're always aware of the environmental conditions around you. Tracking metrics like UV Exposure (UVA, UVB, UVC), Air Quality (eCO2, VOCs), temperature, pressure(altitude) & humidity.
- **Indoor vs Outdoor Comparative Analysis**: Why rely on generic weather reports when you can measure real-time indoor conditions and juxtapose them with the outdoors? With SkySync, you gain insights into how external weather impacts your indoor environment, allowing for optimized comfort and energy savings.
- **Geo-Tagged Data Collection:** With an integrated companion app, every data point SkySync captures is geo-tagged. This not only allows users to understand climatic variations across different terrains and locations but also allows creation of a rich database for deeper environmental analysis.
- **Sustainable Energy:** SkySync incorporates solar cells for energy harvesting. This ensures extended usage without the need for frequent recharges, and more importantly, minimizes the carbon footprint.
- **Personal Safety Alerts**: Beyond just data collection, SkySync offers actionable insights. If a sudden drop in temperature is detected or a storm seems imminent, SkySync, via its companion app and hardware features like beeper, will send real-time alerts ensuring you're never caught off guard.

Block diagram

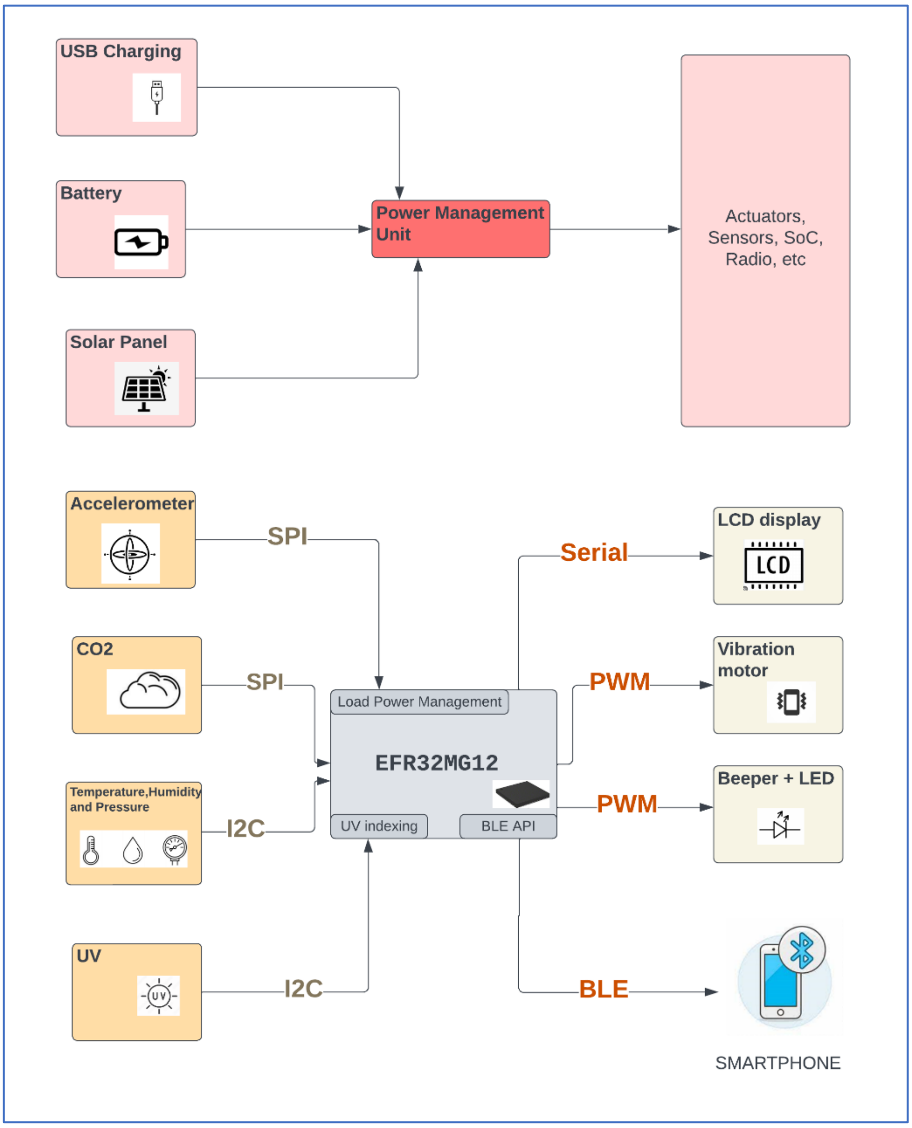


Figure 2 System Block Diagram

This complex EFR32MG12 SoC-based system serves as a sophisticated environmental monitoring platform. It amalgamates data from ENS160, BME280, and AS7331 sensors to provide comprehensive insights into air quality, weather conditions, and UV radiation exposure. Users can access this data through a low-power LCD display or remotely via a smartphone connected through BLE. Additionally, the vibration motor enhances user interaction by providing tactile feedback or alerts, contributing to a holistic and user-friendly experience.

Product Features

Air Quality Index (AQI): The ENS160 sensor will be integrated into our weather application to provide real-time air quality data. Users can access up-to-the-minute air quality information, allowing them to make informed decisions based on the latest data. When used in combination with other data, such as CO2 and VOC levels, the ENS160 sensor can contribute to assessing indoor air quality, which is important for occupant health and comfort.

UV Index: The AS7331 is a low-power, low noise integrated UV sensor. A "Spectral UVA/B/C Sensor" typically refers to a sensor that can measure different segments of the ultraviolet (UV) light spectrum, specifically UVA, UVB, and UVC. The three separated UVA, UVB and UVC channels convert optical radiation signals via photodiodes to a digital result and realize a continuous or triggered measurement.

Load power management: We will be utilizing the MC3419 accelerometer to assess user activity through linear motion, and we are dynamically adjusting the product's measurement frequency based on detected activity levels to optimize data collection and power efficiency. During more intense activities like hiking, the station measures data more frequently and provides it to the user. More intense activities usually entail faster dynamic weather environments.

Temperature, Humidity and Pressure: In our weather station project, we will integrate the BME280 sensor to precisely measure temperature, barometric pressure, and humidity levels in nearby surroundings. This sensor enables us to provide accurate and real-time meteorological data, enhancing the reliability and functionality of our weather monitoring system.

Smartphone app: We're employing Bluetooth Low Energy (BLE) technology to seamlessly transmit real-time weather data from our monitoring station to nearby smartphones. This wireless connection allows users to conveniently access up-to-the-minute weather information on their local smartphone, enhancing their ability to make informed decisions based on current environmental conditions.

Haptic feedback: We will integrate a vibration motor into our system to provide timely alerts to users in the event of adverse weather conditions or deteriorating air quality. This haptic feedback mechanism ensures that users are promptly notified of critical environmental changes, enhancing their safety and awareness.

Display: We're incorporating a low-power LCD display (Sharp 128x128 LS013B7DH03) into our weather station to efficiently showcase real-time weather data at periodic intervals. This energy-efficient display ensures that users can effortlessly access up-to-date meteorological information while maximizing battery life in our portable weather monitoring solution.

Product Specifications

- **CO^2**: Measure VOCs and Carbon Dioxide between Excellent conditions (~400 ppm) to Bad conditions (>1500 ppm) with accuracy of ±15%.
- **Ultraviolet**: UV Index from 1-11+ according to Erythermal Action Curve.
- **Battery Life**: Up to 12 hours of active mode battery life on a single charge, up to 72 hours in low power mode.
- **Activity detection**: Detect and distinguish between low activity levels and high activity levels to better manage energy.
- **Temperature and Pressure:** Measures temperature from the range -40°C to 85°C with accuracy of ±0.5°C and pressure from the range below sea level (300 hPa) to Mt. Everest (1100 hPa) with accuracy of ±2 hPa.
- **Connectivity**: Sync to smartphone app over BLE with range of up to 10 mts.

Extended Features and Stretch Goals

These are some of the additional hardware, firmware & software features we want to implement based on project timeline and challenges.

- **NFC Quick Pairing:** Using passive or active NFC tags, implementing quick BLE pairing using NFC as OOB data.
- **PM2.5 Particulate Matter Measurement**: Particulate Matter addon sensor which can be attached to the main device for improved AQI numbers.
- **Swappable Solar Panel**: Swap to a bigger solar panel when device is stationed.
- **Additional App Features:** Notifications on App, GPS tagging and additional visualization.
- **Cloud Dashboard:** Data storage on cloud and visualization.
- **User Button:** Cycle through all the metrics on the display.
- Simultaneous App Communication with multiple portable weather stations.

Challenges

Miniaturization: Designing compact and portable weather monitoring equipment that houses multiple sensors while maintaining accuracy can be challenging. The nature of sensors, for example UV sensor, which requires a wide field of view to capture the incoming light, will put constraints on the layout of the board. It cannot be placed next to bulky components which limit its view. The solar cells also have similar requirements. This poses a challenge in being able to place all components on the PCB without compromising any of their functionality.

Power Management: Our portable weather stations run on batteries and solar energy. Additionally, due to moving parts (vibration motor) and the nature of some exotic sensors (UV sensor) the peak current drawn at times could come very close to, or exceed, the max current pushed by the PMIC. Balancing power efficiency with data accuracy is a challenge.

UV: In our research, we found a sensor which gives us UV A, B and C spectral values. But this is not equivalent to the UV index that can be readily used. It would be a challenge to map these spectral values to the UV index and thus determine the harmful range.

Sensor Calibration: Ensuring the accuracy of sensor readings is essential for a weather station. Calibrating sensors like UV sensor and CO2 sensor and maintaining calibration over time due to sensor aging can be challenging, as environmental conditions can affect sensor performance.

Data Transmission: Transferring data from the product to a local smartphone poses challenges in terms of pairing and maintaining BT connections. As the BLE radio consumes power for every transmission, finding the sweet spot between conserving energy and providing the user data regularly becomes critical.

Environmental Protection: Weather stations need to withstand various environmental conditions, including rain, humidity, and temperature extremes. Designing a robust and weather-resistant enclosure is crucial for long-term outdoor use. A 3D printed case with adequate protection might be necessary.

Cost Management: Weather has a lot of parameters, and each factor needs a sensor of its own to measure it. Developing a portable weather station with high-quality sensors and features can be expensive. Additionally, we will have to make choices between going for a more critical environment factor for a costlier sensor versus going for multiple less-impactful environmental factors with cheaper sensors.

Testing and Validation: Rigorous testing and validation under different weather conditions is necessary. Figuring out a way to simulate these conditions, without causing any harm to any member of the team, will be tricky. Fortunately, residing in Boulder, CO, we experience all sorts of weather conditions and that makes this challenge slightly easier to navigate.

Component Selection and Specifications

SYSTEM FUCNTIONS	COMPONENT	WEBSITE LINK	DATASHEET & Digikey Part Number	Dimension	COST
SoC	MIGHTY GECKO	EFR32MG12P432F1024GM48-C	DATASHEET 336-4227-ND	7mm x 7mm	11.79
BATTERY	LI-ON BATTERY	ASR00036	DATASHEET 1832-1052-ND	48.0mm x 30.0mm x 6.0mm	6.37
ENERGY HARVESTING	SOLAR CELL	SM111K10L	DATASHEET SM111K10L-ND	42.0mm x 35.0mm x 2.0mm	9.39

SYSTEM FUCNTIONS	COMPONENT	WEBSITE LINK	DATASHEET & Digikey Part Number	Dimension	Interfaces	Current/Power Consumption	Operating voltage	COST (USD)
SENSORS	MC3419 *Backup (ADXL343)	MC3419	DATASHEET35 02-MC3419CT-ND	2 mm × 2 mm × 0.92 mm	I2C SPI	• Standby current 4 µA • WAKE state current 77 µA	1.7 V to 3.6 V	1.66
	BME280	BME280	DATASHEET82 8-1063-1-ND	2.5 mm x 2.5 mm x 0.93 mm	I2C SPI	• 1.8 µA @ 1 Hz humidity and temperature • 2.8 µA @ 1 Hz pressure and temperature • 3.6 µA @ 1 Hz humidity, pressure and temperature • 0.1 µA in sleep mode	1.71 V to 3.6 V	6.42
	ENS160	ENS160	DATASHEET26 18-ENS160-BGLMCT-ND	3 mm x 3 mm x 0.9 mm	I2C SPI	• DEEPSLEEP mode 0.01 mA • IDLE mode 2 to 2.5 mA • STANDARD mode 29 mA	1.71 V to 1.98V	10.2
	AS7331	AS7331	DATASHEET49 91-AS7331_MOLG A16LFT&RDPC T-ND	2.6 mm x 3.65 mm	I2C	• Active mode during measurement 1.5to 2 mA • Standby state 970 µA • Power down state 1 µA	2.7 V to 3.6 V	10.8
ACTUATOR S/ OUTPUTS	DISPLAY	LS013B7D H03	DATASHEET42 5-2903-ND	23.0 mm x 23.04 mm	Serial	• 12-130 uW	2.7 V to 3.3 V	11.9
	VIBRATION MOTOR	VCLP1020 B002L	DATASHEET16 70-VCLP1020B002 L-ND	Dia (10.00mm)		• Max 30 mA	2.5 V to 3.5 V	2.12

Project Week 1 Update

Status report

After receiving feedback from the Professors and TAs, we finalised the SOC and sensors. By moving the accelerometer and vibration motor as our stretch goals, we decided to reduce the complexity. Moreover, we are leaning towards the BG22 series since our application is only BLE based. We have also created a common git repo to keep track of the tasks scheduled and upload the work done.

Upcoming Activities:

- We will work and research on Battery and power management selection next week.
- Order modules for preliminary SBB testing.

As per the schedule assigned by the professor at the beginning of the project, and timeline planned by us, we are on track. We do not have any hurdles at this point, but we do foresee some as we dig deeper into our project design. The TAs have been guiding us as and when necessary for all project planning activities.

Use Case model

Every sensor data point is sampled every X minute, data is processed and sent over BLE to the Central Device (smartphone). Hence, every X^{th} minute the SoC will wake up from deep sleep mode (EM2) and be awake (EM0) for a certain duration, enough to read data from the sensors and transmit it to the central device, and then go back to deep sleep. This constitutes one read and transmit cycle. This repeats every X^{th} minute. For this calculation we have assumed X to be 10 minutes. This assumption is just to get a rough idea of energy consumption.

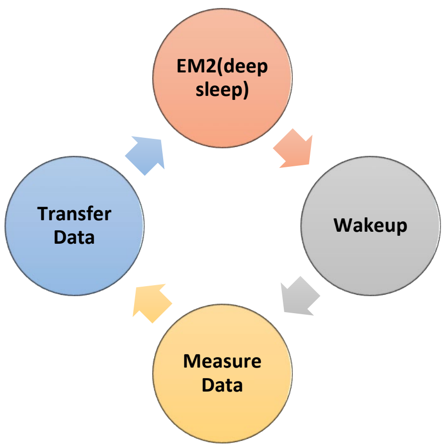
This use case model will be further developed as we develop the features further to determine optimal sampling rates and user inputs. According to our current estimates, the sensor sampling will cycle between 5, 10 and 20 minutes. This gives the user the option of using our product in dynamically changing environments.

As of now it is assumed that all sensors are measured once in 10 minutes. For the actual implementation different sensors might be measured at different intervals. It makes more sense to measure Temp/Pressure/Humidity and UV more frequently compared to AQI. TBD based on the final application.

Worst case average current consumption has been assumed for the SoC based on the previous currents measured for IoT course projects. This was more realistic than using datasheet numbers.

Currently, we also assume that the measurement cycle repeats indefinitely.

Assuming a 10-minute cycle, 30s in EM0(run) mode and 570s in EM2(deep sleep) mode with Radio on. Below is simple state diagram of all the states the SoC cycles through, in our project. This is cyclic for every read and transmit cycle.



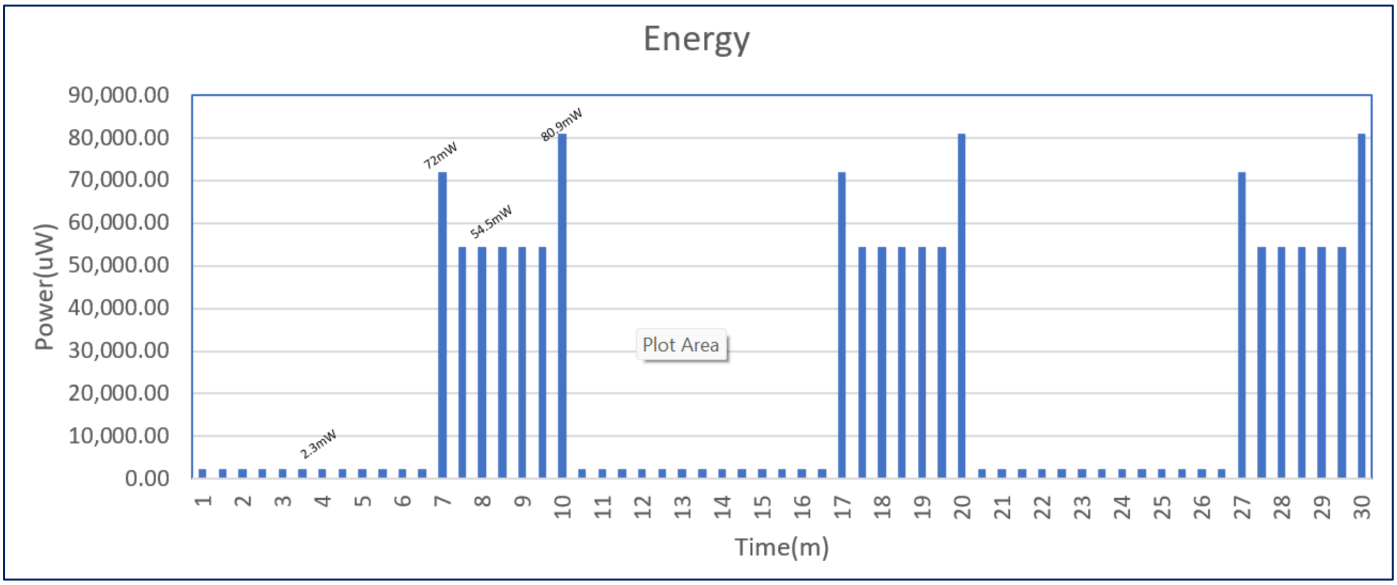
Part selection of all major components

COMPONENT	SPECIFICATIONS/FEATURES
EFR32BG22C224F512GM32-C	• Features a high-performance 32-bit ARM Cortex-M33 processor, running at 76.8 MHz. • Offers up to 512 kB of flash program memory and up to 32 kB of RAM data memory. • Supports 2.4 GHz radio operations.
LI-ON BATTERY	• Rechargeable battery with a capacity of 850 milliampere-hours (mAh). • Nominal voltage of 3.7V. • Discharge Cut-off Voltage is 2.4V.
SOLAR CELL	• Monocrystalline silicon technology. • Typical voltage is 5.58 V, and a current is 43.9 mA at the point of maximum power (Pmpp). • Short-circuit current (Isc) of 46.7 mA and Open-circuit voltage of 6.91 V.

Sensor/actuator selection

SENSOR	REASON OF SELECTION/FEATURES
ENS160	• **Provides multiple indoor air quality (IAQ) metrics: TVOC, eCO2, AQI.** • Compatible with both I2C and SPI communication interfaces.
AS7331	• **Allows for distinct measurements of UVA, UVB, and UVC radiation, providing comprehensive UV data.** • Supports the use of up to four AS7331 sensors simultaneously on the same I²C bus, allowing for versatile UV monitoring setups. • Designed for low-power operation and includes power management features such as Power-on Reset, Power-down, and standby modes. • Employs three separate UV detectors with interference filter technology, enabling precise measurement of UVA, UVB, and UVC radiation
BME280	• **Widely used and combines multiple environmental sensors in a single compact package, including a barometric pressure sensor, a humidity sensor, and a temperature.** • Supports I²C communication at speeds of up to 3.4 MHz and SPI communication with both 3-wire and 4 wire modes at speeds of up to 10 MHz. • Flexibility to independently enable or disable the humidity sensor and pressure sensor.

Energy mode bar chart



As mentioned in our use case, a 10-minute cycle has been assumed for the intent of power calculations. The system is in deep sleep (EM2) mode. At the 7th minute, the system wakes up to trigger a measurement of ENS160's sensor data. This is done as the sensor needs about 3 minutes to produce valid data. Hence, there is a small peak at the 7th minute. The SoC is in EM0 mode and the ENS160 is turned on and is in measurement mode. After triggering the measurement, via I2C, the SoC goes back to sleep mode and hence the slight drop in power. From the 7th minute to 9.5th minute, the system does not have any task at hand and goes back to deep sleep. At the 9.5th minute, the system wakes up for the following tasks:

- Read data from the ENS160 sensor, which we triggered previously.
- Trigger and read data from the BME280 as well as AS7331 sensors, via SPI and I2C respectively.
- Make necessary data processing and alert user.
- Transmit data over Radio to a central device, here smartphone.

During this period, the system will be consuming max current. After successful transmission, the system goes back to deep sleep mode. End of one measurement cycle. This repeats indefinitely.

Power Calculations

SoC

Assuming a 10-minute cycle, 30s in EM0 mode and 570s in EM2 mode with Radio on

EM2 - Full RAM retention and RTC running from LFRCO in precision mode.

State	Current (mA)	Power (mW)	Weight
EM2	0.7	2.31	0.95
EM0	6	19.8	0.05

Weighted Average of Current = **0.965mA**, at 3.3V Weighted Average Power = **3.1845mW**

BME280 Humidity, Temperature, Pressure

In weather monitoring mode.

State	Current (mA)	Power	Weight
Deep Sleep	0.0001	0.33 uW	0.98
Active	0.7	2.31mW	0.02

Needs about 8ms to wake up and measure data.

Considering one data measurement every 10 minutes.

Weighted Average Current = **0.01437mA**, at 3.3V Weighted Average Power = **0.0474mW**

ENS160 AQI, eCO2, TVOC

State	Current (mA)	Power	Weight
Deep Sleep	0.01	18 uW	0.7
Active	29	52.2 mW	0.3

The sensor needs 3 minutes to warm up, considering one measurement every 10minutes As of now we are assuming that this sensor will be powered at 1.8V using an LDO.

Weighted Average Current = **8.7mA**, at 1.8V Weighted Average Power = **15.66mW**

AS7331 UV Index

State	Current (mA)	Power	Weight
Deep Sleep	0.001	3.3 uW	0.98
Active	2	6.6 mW	0.02

Needs about 70ms to wake up and measure data.

Considering one data measurement every 10 minutes.

Weighted Average Current = **0.0401mA**, at 3.3V Weighted Average Power = **0.13233mW**

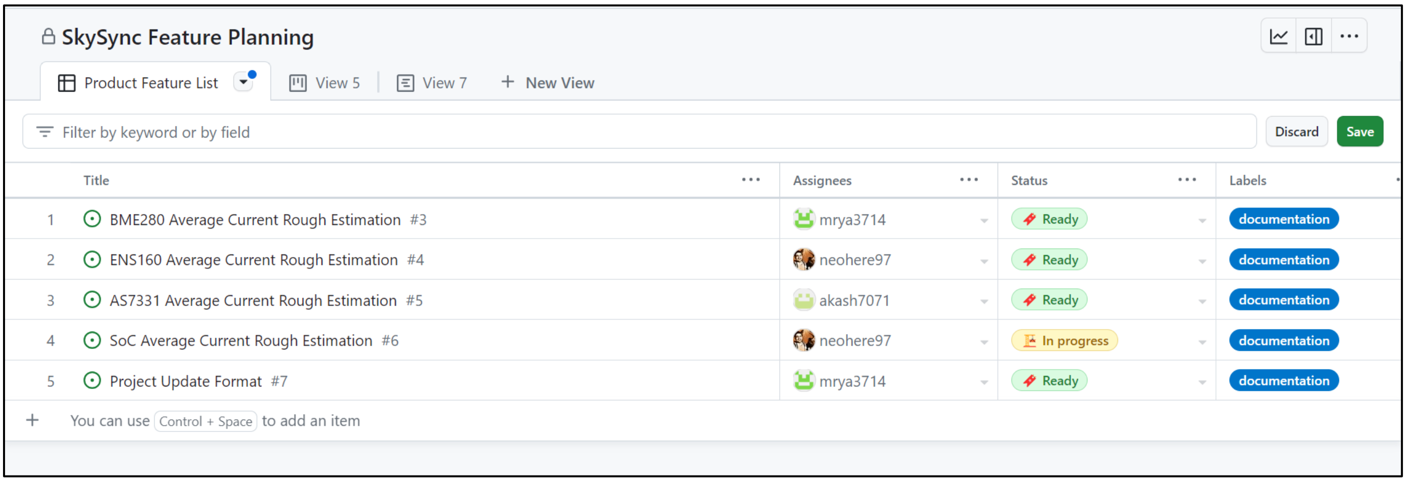
Combined Average Current and Power

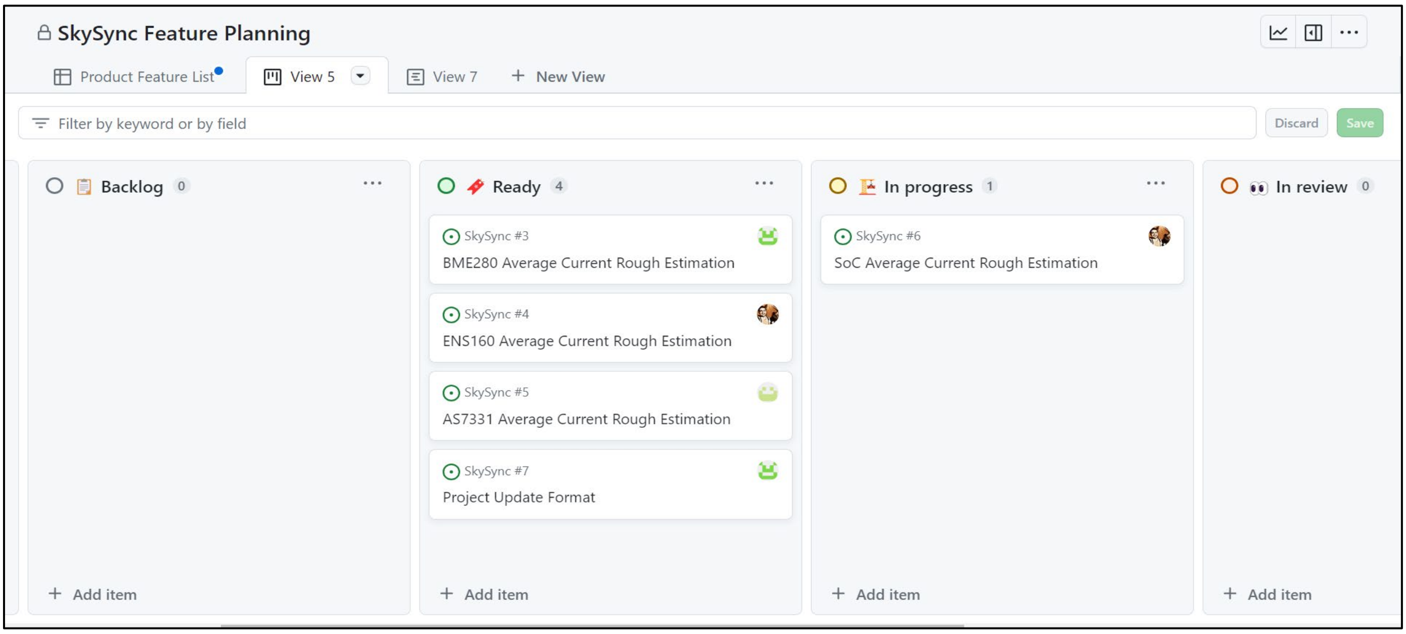
Device	Avg Current (mA)	Voltage (V)	Avg Power (mW)
EFR32 BLE SoC	0.965	3.3	3.1845
BME280	0.0143	3.3	0.0474
AS7331	0.401	3.3	0.1323
ENS160	8.7	1.8	15.66
Total	--	--	**19.024**

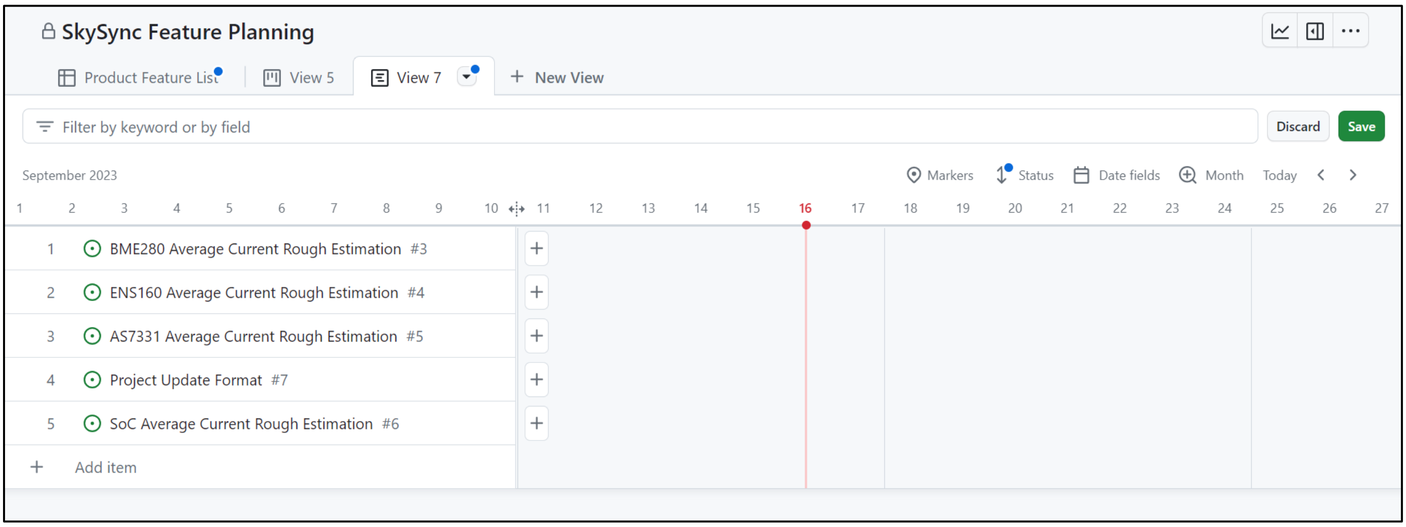
Gantt chart demo

Created a Gantt chart on GitHub. The left side outlines a list of tasks, assignees, status, markers with schedule that visualize work.

[Github Gantt chart]







Miscellaneous Updates

- LGA package PCB footprint designing for ENS160.

Project Week 2 Update

Status report

With further discussion on Power Management Units and Energy Storage Elements, a decision has been made on the usage of Li-Po batteries over super capacitors. With effective collaborations with the SAs, it has been decided to move ahead with BQ25570 as our PMIC, which dons the role of energy harvesting IC, Battery Management Unit as well as buck and boost converters. A versatile PMIC reduces the need of additional components on the board. Additionally, 3.3V has been decided to be powering all the components on the board, after considerations on the heat generation and additional circuitry involved with LDO circuits to step down to 1.8V. A few course-corrective measure have been taken from the previous update as well as feedback received from the Project update.

Project is on schedule and regular feedback from professors and assistance from the SA team has been vital to that. Expecting roadblocks soon, especially for the assumed parts of the project.

Upcoming Activities:

The coming week has a lot of development and testing.

- The dev kits and the sensor modules will be received by us, and developing isolated circuits for sensor measurement will be the primary focus.
- Additionally, usage of shared vs separated I2C SPI busses will be tested and validated.
- Some software elements like timers, external interrupts, etc for the EFR32BG22 will be developed and tested with corresponding sensors.
- We will work and research on Battery and power management selection next week.
- Order modules for preliminary SBB testing.

As per the schedule assigned by the professor at the beginning of the project, and timeline planned by us, we are on track. We do not have any hurdles at this point, but we do foresee some as we dig deeper into our project design. The TAs have been guiding us as and when necessary for all project planning activities.

Energy Storage element selection

One of the sensors in our application consumes about 29mA of current constantly for 3 minutes straight. This means the average current of the system is quite high and will require more energy for the expected duration of usage. Due to higher energy storage requirements and charging efficiency of Lithium-Ion Polymer batteries over Super capacitors, we decided to go ahead with the former, for our product. Below are some reasons behind our selection of ASR00036Li Li-ion Polymer 850mAh Battery for our energy storing needs.

Size: coming in at 48mm, perfect for our application. It is small enough in size to fit onto our board and be portable and still large enough to power our system for sufficient duration.

Voltage rating: With maximum charging voltage at 4.2V and nominal voltage at 3,7, it will serve all our power needs. Especially the high current consuming ENS160 sensor.

Current rating: With Peak current at 0.5C or 425mA, our system will be able to draw 41mA, its peak current, without breaking a sweat.

Capacity: Based on our calculation, the 850mAh capacity will outlast our predicted 12-hour battery life. Even accounting for the battery degradation, our product will deliver the expected battery life with ~85% loss in battery capacity.

Operating environmental conditions: For a weather application, the physical capabilities of the battery are of utmost importance. We have chosen a battery which can withstand up to -10 ◦C when store and deliver accurate results between 0 ◦C to +45 ◦C.

Average current calculation

System-On-Chip:

State	Current (mA)	Power (mW)	Weight
EM2	0.7	2.31	0.95
EM0	6	19.8	0.05

Weighted Average of Current = 0.965mA, at 3.3V Weighted Average Power = 3.1845mW.

BME280 Humidity, Temperature, Pressure:

State	Current (mA)	Power	Weight
Deep Sleep	0.0001	0.33 uW	0.98
Active	0.7	2.31mW	0.02

Weighted Average Current = 0.01437mA, at 3.3V Weighted Average Power = 0.0474mW.

ENS160 AQI, eCO2, TVOC:

State	Current (mA)	Power	Weight
Deep Sleep	0.01	18 uW	0.7
Active	29	52.2 mW	0.3

Weighted Average Current = 8.7mA, at 1.8V Weighted Average Power = 15.66mW.

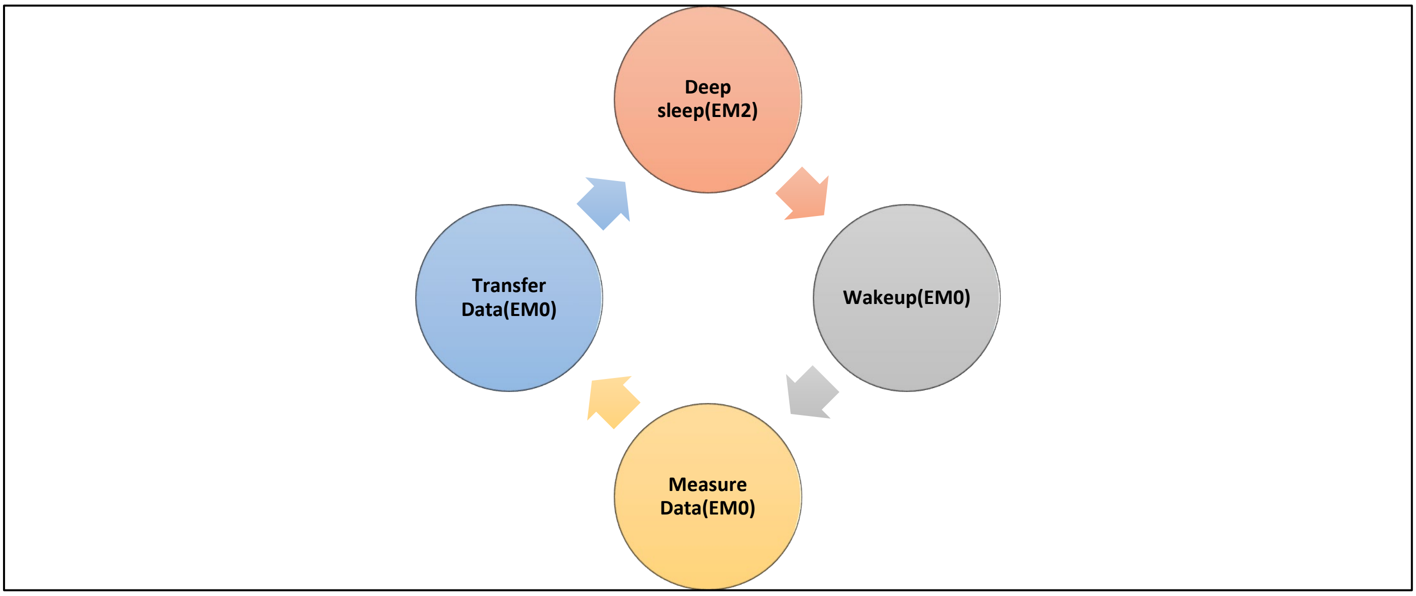
AS7331 UV Index:

State	Current (mA)	Power	Weight
Deep Sleep	0.001	3.3 uW	0.98
Active	2	6.6 mW	0.02

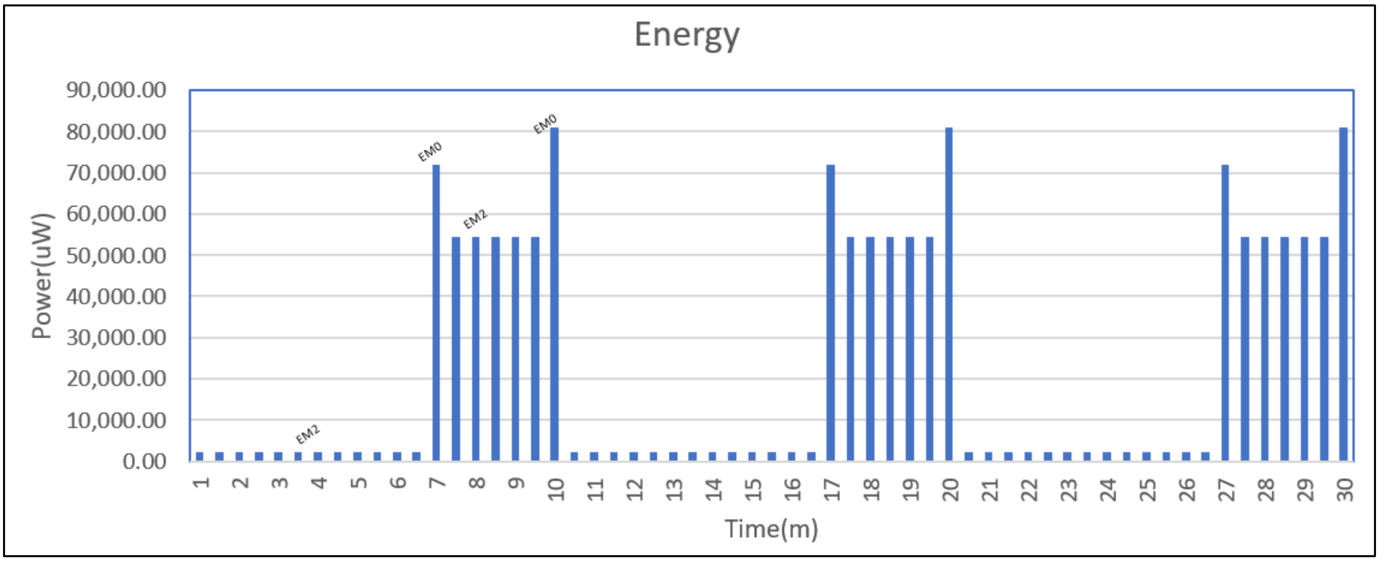
Weighted Average Current = 0.0401mA, at 3.3V Weighted Average Power = 0.13233mW.

Use Case and their modes.

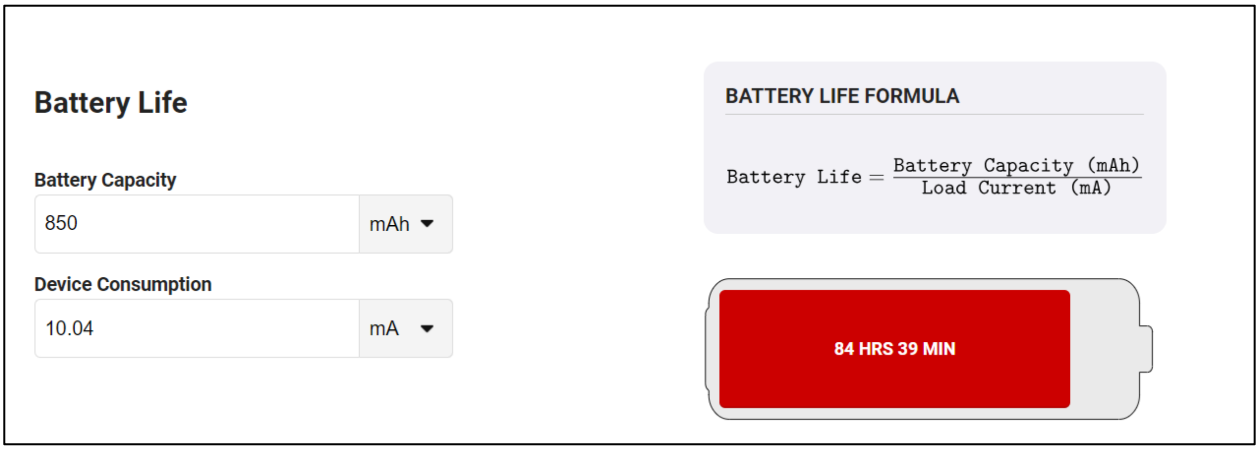
Our product is mainly run in two different energy modes EM0 and EM2. Assuming a 10-minute cycle, it operates for 30s in EM0(run) mode and 570s in EM2(deep sleep) mode with Radio on. Below is simple state diagram of all the states the SoC cycles through, in our project. This is cyclic for every read and transmit cycle.



During the EM0, the SoC will wake up sensors, initiate measurements, read data after measurements and transfer via Radio to a local smartphone. It is obvious that this is where peak current is consumed. The system goes to EM0 twice. Once to wake up a sensor, which has a 3-minute measurement period, and the second time for rest of its operations.



Accounting for a 10-minute cycle, the average current consumed is 10.04 mA, arrived at by adding up average currents from individual components. The Battery we chose delivers 850mAh on one full charge. Below is an estimate of the battery runtime when used as a energy storage element in our product.



At 84 Hrs and 39 Min, the battery life from one full charge is ~7x of our needs which is specified at 12 Hours. As per the datasheet of the Li-Ion Polymer battery we chose, the battery will retain >85% of its minimum capacity.

3.2 Electrical Performance

Item	Measuring Procedure	Requirements
Cycle Life (25℃)	First charge with a constant current of 0.5C to 4.2V and a constant voltage of 4.2V until the charge current is less than or equal to 0.01C. Leave it aside for 10 minutes. Then discharge to 2.75V with a current of 0.5C - leave it aside for another 10 minutes. Repeat the above steps 300 times. The capacity of the cells should be higher than 80% of the minimum capacity.	Cycle life ≥ 300 cycles

An average working day is about 9 hours. Considering commuting and other errands in a day, an average person is expected to be outside/ away from the reach of a charging station at the max of 12 hours. We will assume that an average consumer uses the product for 12 hours a day on the stretch. On a new battery, that should give us about 7 days of usage over a single charge.

For a 10-minute read and transfer cycle, with a 12-hour continuous operation under optimal environment conditions, the max usage of the weather station on a single full charge, ideally, can be calculated as follows.

Max usage (in days) = Total possible hours of operation/ Use case (in Hrs.)

= 84 Hrs. 39 Min/ 12 Hrs.

= ~7 Days

With a 7 days recharging cycle, and a 300-cycle battery degradation constraint, at the end of 300 life cycles, the product would have been in operation for 300x7=2100 days or 5.75 Years. At the end of 5.75 years, the battery capacity would be about 720mAh. This is beyond product lifecycle.
Total energy required between charging (E) = V * I * t

- *V = Voltage at which this energy is consumed*
- *I = average current at which the energy source is consumed*
- *t = time for which energy is consumed*

*E = 3.7V * 10.04 mA * 12 Hours*

E = 1604 J

Hence, over a 12-hour window our product would consume 1.6kJ of energy.

Charging Time: The ASR00036Li Li-ion Polymer 850mAh Battery supports up to 0.5C of charging speeds over traditional USB interface. At 425mA per hour, the battery would take up to 2 hours ideally to go from 0-100%.

Charging Time (in hours) = (Battery Capacity in Ah) / (Charge Current in A)

*= 850/ (0.5*1)*

= 2 Hours

This is a simplified calculation, and the actual charging time may vary slightly due to factors like charging efficiency, initial battery voltage, and the charger's characteristics.

PMU selection

We are going to use Solar module for energy harvesting and LI-ON battery cell for energy storage. Circuitry will be operated within 3.6V – 4.2V battery voltage range.

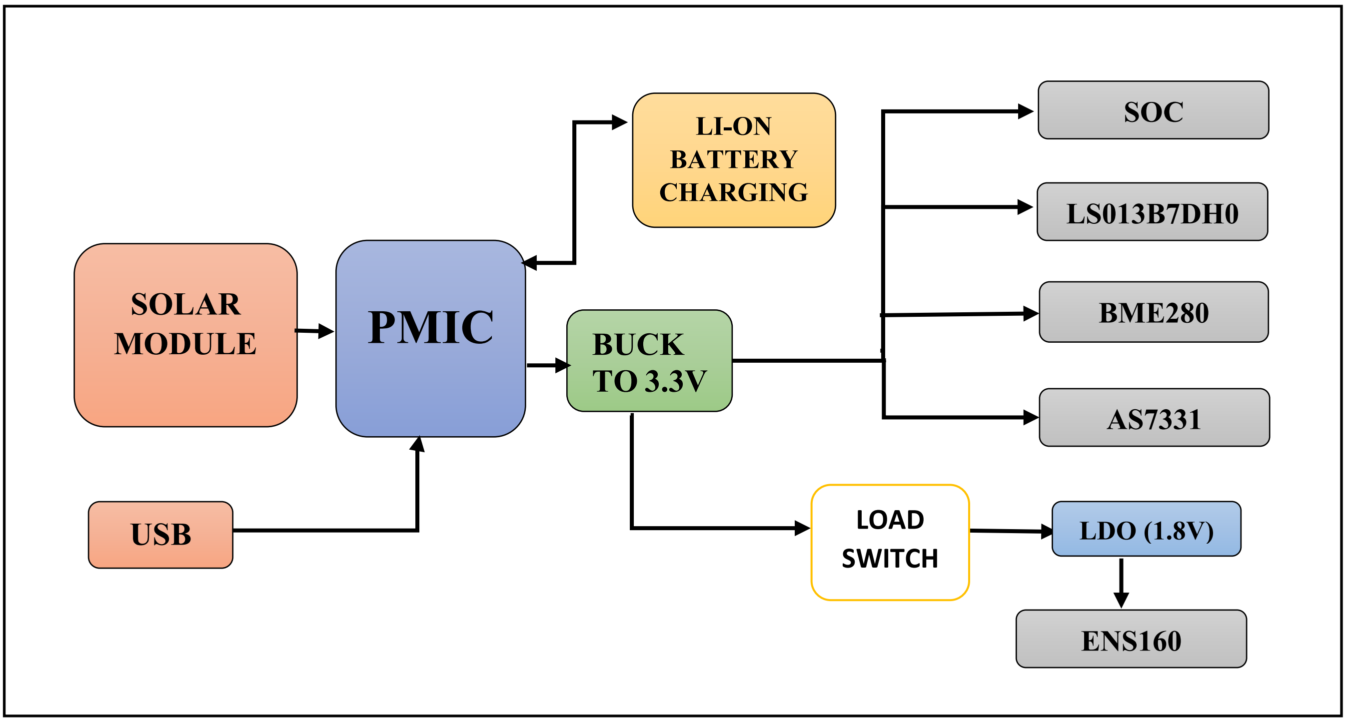
Factors considered for the selection for Solar module and battery cell:

COMPONENT	Important Features	Website Link	Datasheet & Digikey Part number
SOLAR CELL (Energy harvesting)	• VOC open circuit voltage 6.91 V • ISC short circuit current 46.7 mA • Vmpp voltage at max. power point 5.58 V • Impp current at max. power point 43.9 mA	SM111K10L	DATASHEET SM111K10L-ND
LI-ON BATTERY (Energy storage)	• Nominal Voltage 3.7 V • Charge Voltage 4.2 V • Cut-off Voltage 2.4 V	ASR00036	DATASHEET 1832-1052-ND

Module requirements and features considered:

COMPONENT	Minimum Vinmax	Maximum Vinmin	Planned Voltage supply
EFR32BG22C224F512GM32-C	1.71	3.8	3.3
ENS160	1.71	1.98	1.8
AS7331	2.7	3.6	3.3
BME280	1.71	3.6	3.3
LS013B7DH03	-0.3	3.6	3.3

According to the supply voltage and peak output current requirements of the sensors and SOC, we designed the power management Unit.



PMIC and LDO selection:

COMPONENT	Important Features	Website Link	Digikey Part number
PMIC (BQ25570)	• Cold-Start Voltage: VIN ≥ 600 mV • Continuous Energy Harvesting from VIN as low as 100 mV • Supports Peak Output Current up to 110 mA(typical) (Buck converter) • Energy can be Stored to Re-chargeable Li-ion Batteries, Thin-film Batteries, Supercapacitors, or Conventional Capacitors	bq25570	296-37014-1-ND
LDO (LP5907)	• Input voltage range: 2.2 V to 5.5 V • Output voltage range: 1.2 V to 4.5 V • Can supply up to 250 mA output current (EN5160 consumes approx. 29mA in active mode)	LP5907	296-41463-1-ND

We plan to use the BQ25570 boost charger for continuous energy harvesting via a solar module. The harvested energy will be stored in a lithium-ion battery. Additionally, we will utilize a buck converter within the PMIC to step down the voltage to 3.3V, which will power two sensors, a display, and the system-on-chip (SoC).

For the ENS160 sensor, it's important to note that the maximum supply voltage it can handle is 1.98V. To meet this requirement, we have decided to incorporate a Low Dropout Regulator (LDO) to configure the output voltage to 1.8V. This 1.8V supply voltage will be sufficient to power the ENS160 sensor.

Moreover, PMIC can also be operated with USB (TBD).

- Does the digital / analog portion of the board require a fixed voltage?
  Yes, for instance BME680 has a VDDIO pin which enables and disables I2C bus. It requires minimum VIH (2.64V) and VIL (0.66V) for logical high-low voltages.

- Will the Energy Source voltage always be above the circuitry voltage?
  Yes, we are planning to use VBAT, VBAT_OK and VBAT_OV pins of PMIC for setting the battery undervoltage and overvoltage threshold for the indication.

Miscellaneous Updates

- As per feedback from the professor, the Gantt chart has been updated with future task to represent the project timelines more accurately. The major checkpoints have been assigned to the team and the smaller tasks under each heading will be broken down for modularity and assigned to individual members.
  Gantt chart git link
- The work on separate vs common busses for both I2C and SPI busses will be taken up in the following week. As per our current design, common busses will lead to difficulty in load power management as one of the ICs is required to be on for longer than the others.

Project Week 3 Update

Status Report:

We have decided to change the solar panel because its open-circuit voltage is 6.91V, which exceeds the maximum input DC voltage of 5.1V for the BQ25570. This voltage discrepancy could potentially damage the BQ25570 or lead to inefficient energy conversion. Therefore, replacing the solar panel is necessary to ensure compatibility and proper operation. Furthermore, as a preventive measure, we have opted to incorporate a load switch for the ENS160. The load switch will enable us to easily activate or deactivate power to the ENS160 as needed, which can be particularly useful in preventing issues or optimizing power consumption in various scenarios.

Upcoming activities:

- Commence work on the development kits.
- Finish creating the Component Library and Footprint Design.
- Wrap up the schematic design for the entire system.

Several corrective measures have been implemented based on the previous update and feedback received during the project update. Currently, the project is proceeding as planned, and the revisions have been integrated following the input from both professors and the SA team. Tasks have been created and updated on Gantt Chart.

Sizing storage based on recharge requirements:

- According to the datasheet, the maximum charging current is 110mA. With our current battery rated at 850mAh and charge current of 1C, battery can accept up to 850mA of charging current, but limited by our current choice of PMIC.
- Based on our current choices, charging can take up to 8+ hours based on the theoretical numbers when charging indoors. When outdoors, the solar panel (peak power **184mW** vs **19mW** for our device) can drive the load and charge the battery, hence reducing the battery discharge rate significantly. Even in cloudy conditions, solar panel will still generate enough power to reduce battery discharge significantly.
- Ultimately, the storage size for our product was chosen based on the lifetime expected, power requirements, dimensions of the product and relative price of the batteries of different capacities.
- Further refinements can be made in the choice of PMIC which can allow higher charging currents or charge the battery with a standalone USB charging circuitry with currents up to 500mA. Potentially we are looking at a separate USB charging IC's in parallel configuration with the PMIC.

Verified C-rate and battery solution:

• What is the C-rate of your specified battery?

0.5C or 425mA for charging.

Charging Time: The ASR00036Li Li-ion Polymer 850mAh Battery supports up to 0.5C of charging speeds over traditional USB interface. At 425mA per hour, the battery would take up to 2 hours ideally to go from 0-100%.

Charging Time (in hours) = (Battery Capacity in Ah) / (Charge Current in A)

*= 850/ (0.5*1)*

= 2 Hours

This is a simplified calculation, and the actual charging time may vary slightly due to factors like charging efficiency, initial battery voltage, and the charger's characteristics.

However, the charging of the battery is limited by the amount of current the PMIC can push. The max current this chip can push is 100mA for charging the circuit. Bringing this into our calculations, the charging time changes as follows:

Charging Time (in hours) = (Battery Capacity in mAh) / (peak charge current in mA)

= 850/ (100)

= 8.5 Hours

2.7	Standard Charge Current	425	mA	0.5C
2.8	Maximum Charge Current	850	mA	1.0C
2.9	Maximum Discharge Current	850	mA	1.0C

• What is the peak discharge rate out of the battery in your application?

1C or 850mA during discharge.

• Based on your lithium battery discharge curve, what is the lowest nominal voltage? What will be the battery cut-off voltage of your circuit?

2.2	Nominal voltage	3.70	V	
2.3	AC Impedance Resistance	≤180	mΩ	(with PCB)
2.4	Discharge Cut-off Voltage	2.40	V	

Based on datasheet of the ASR00036, for a 850mA current drain, the nominal voltage will be 3.7V. The battery's cut-off voltage is 2.4V.

• Will this nominal voltage work using a buck only solution or is a buck-boost required?

A buck only converter will be sufficient as we intend to operate the system at 3.3V and the nominal voltage supplied is 3.7V.

• Does your PMU support a low battery discharge cut-off voltage?

Yes,

VBAT_UV	Under-voltage threshold	VBAT decreasing	1.91	1.95	2.0	V

• If so, what is the cut-off voltage that you will program or set?

The PMIC chosen by us does not support user programmable Under Voltage (UV) cut-off voltage. But it does have a internally set UV cut-off voltage, 1.95V. This is above our desired cut-off voltage of 1.8V.

Feature Description (continued)

7.3.2 Battery Undervoltage Protection

To prevent rechargeable batteries from being deeply discharged and damaged, and to prevent completely depleting charge from a capacitive storage element, the boost charger has an internally set undervoltage (VBAT_UV) threshold plus an internal hysteresis voltage (VBAT_UV_HYST). The VBAT_UV threshold voltage when the battery voltage is decreasing is internally set to 1.95V (typical). The undervoltage threshold when battery voltage is increasing is given by VBAT_UV plus VBAT_UV_HYST. For the VBAT_UV feature to function properly, the system load should be connected to the VSTOR pin while the storage element should be connected to the VBAT pin. Once the VSTOR pin voltage goes above VBAT_UV plus VBAT_UV_HYST threshold, the VSTOR pin and the VBAT pins are effectively shorted through an internal PMOS FET. The switch remains closed until the VSTOR pin voltage falls below the VBAT_UV threshold. The VBAT_UV threshold should be considered a fail safe to the system and the system load should be removed or reduced based on the VBAT_OK threshold which should be set above the VBAT_UV threshold.

Worst case timing information for communication bus:

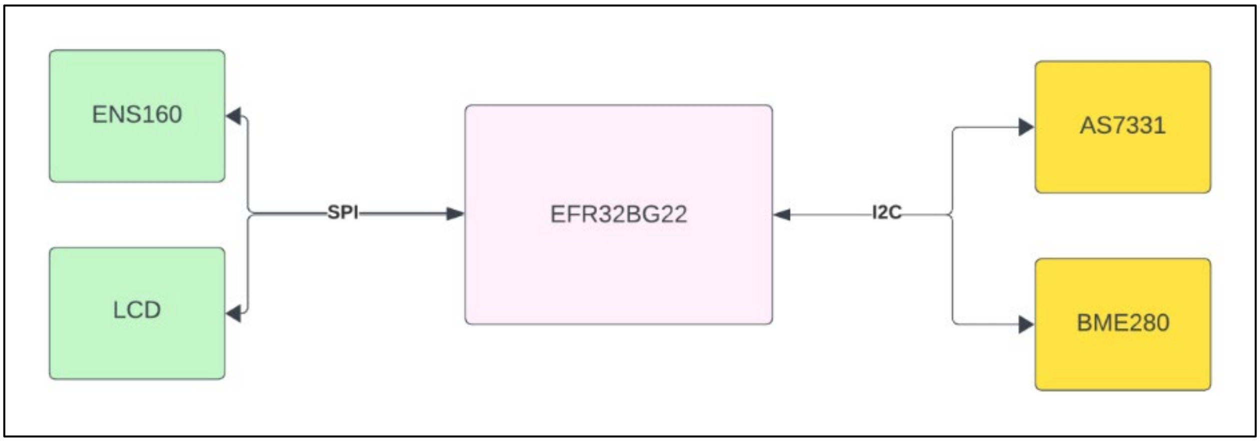


Figure 1 Sensors and their communications busses.

There are three sensors and an LCD display. Above is a simple block diagram explaining the protocol on which they communicate with the SoC and information about their busses. The AS7331 only works on I2C and the low power LCD display can communicate over SPI only. This makes the choice of their protocol simple. The ENS160 and the BME280 both work over I2C and SPI. The choice of their protocols and busses needed further investigation.

The ENS160 is a high current consuming sensor. It needs to be turned on 3 minutes before it can start outputting measurements and while its on for those three minutes, it consumes over 29mA of current! For this reason, it was put on the SPI bus which consumes lesser power overall. The usage of a load switch will enable to turn off the ENS160 as and when required as well as allowing the LCD to have a shared bus with the former.

The AS7331 and the BME280 both work over I2C. They also do not need a lot of time to from boot to start delivering measurements. With both of them consuming active currents in range of uA, their power consumption can be managed even with a higher energy consuming I2C bus. Due to these reasons, both of them will share the same I2C bus.

ENS160 SPI timing specifications

14.2.2 SPI timing information

Table 13: SPI Timings

Parameter	Symbol	Condition	Min	Typ	Max	Unit
SPI Clock (SCLK) Frequency	FSCLK				10	MHz
CSn falling to MISO Enabled	TEN	25pF load			20	ns
CSn rising to MISO Disable	TDIS	25pF load			20	ns
MOSI Setup Time before SCLK	TSUPI		15			ns
MOSI hold time after rising SCLK	THLDI		15			ns
CSn low to first rising SCLK	TLEAD		20			ns
Last SCLK low to CSn high	TLAG		20			ns
SCLK High Time	TSCLKH		40			ns
SCLK Low Time	TSCLKL		40			ns
SCLK falling to MISO Valid	TVALID	25pF load			40	ns

MOSI setup time: 15nS

MOSI hold time: 15nS

LCD display SPI timing specification:

6-3) Input Signal Basic characteristics

Table 6-3-1 (Ta=25°C, SCS, SCLK, SI, DISP, EXTCOMIN=3.0V, VDD=3.0V, VSS pin=0V)

Pin name	Item	Code	Min	Typ.	Max	Unit	Notes
SCS	Frame frequency	fSCS	54		65	Hz	(*1)
SCLK	Clock frequency	fSCLK	-	1	1.1	MHz	
-	Vertical period	tV	15.38		18.52	msec	
-	COM frequency	fCOM	27		32.5	Hz	

(*1) Please use a frame frequency in the range where there are no problems with the display quality.

Table 6-3-2 Input signals (Ta=25°C, SCS, SCLK, SI, DISP, EXTCOMIN=3.0V, VDD=3.0V, VSS pin=0V)

Pin name	Item	Code	Min	Typ.	Max	Unit	Notes
SCS	SCS rise time	trSCS			50	nsec	
	SCS fall time	tfSCS			50	nsec	
	SCS Highwidth	twSCSH	153.45			μsec	Data update mode
			22.55			μsec	Display mode
	SCS Low width	twSCSL	6			μsec	
	SCS set up time	tsSCS	6			μsec	
	SCS hold time	thSCS	2			μsec	
SI	SI rise time	frSI			50	nsec	
	SI rise time	trSI			50	nsec	
	SI set up time	tsSCS	227			nsec	
	SI hold time	thSI	525			nsec	
SCLK	SCLK rise time	trSCLK			50	nsec	
	SCLK fall time	tfSCLK			50	nsec	
	SCLK High width	twSCLKH	404.55	450		nsec	
	SCLK Low width	twSCLKL	404.55	450		nsec	
EXTCOMIN	EXTCOMIN frequency	fEXTCOMIN	54		65	Hz	(*1)
	EXTCOMIN rise time	trEXTCOMIN			50	nsec	
	EXTCOMIN fall time	tfEXTCOMIN			50	nsec	
	EXTCOMIN High width	twEXTCOMIN	2			μsec	
	EXTCOMIN set up time	tsEXTCOMIN	5			μsec	
	EXTCOMIN hold time	thEXTCOMIN	0			μsec	
DISP	DISP rise time	trDISP			50	nsec	
	DISP fall time	tfDISP			50	nsec	

Worst setup time: 227nS

Worst hold time: 525nS

AS7331 I2C timing specification

7.8.1 I²C Timing Characteristics

Figure 39:
I²C Slave Timing Characteristics of the AS7331

Symbol	Parameter	Conditions	Min	Typ	Max	Unit
f_{SCL}	I²C Clock Frequency at SCL.	$R_{PULLUP} \geq 820\ \Omega$ $CL_{(SCL,\ SDA)} \leq 400$ pF			400	kHz
t_{HIGH}	SCL High Pulse Width.		0.6			µs
t_{LOW}	SCL Low Pulse Width.		1.3			µs
t_R	SCL and SDA Rise Time.				0.3	µs
t_F	SCL and SDA Fall Time.				0.3	µs
$t_{HD;STA}$	Hold Time Start Condition.		0.6			µs
$t_{SU;SDA}$	Setup Time Start Condition.		0.6			µs
$t_{HD;DATM}$	SDA Data Hold Time (Master).	Data transfer from master to slave	0.02			µs
$t_{HD;DATS}$	SDA Data Hold Time (Slave).	Data transfer from slave to master	0.3		0.9	µs
$t_{SU;DAT}$	Data Setup Time.		0.1			µs
$t_{SU;STO}$	Setup Time Stop Condition.		0.6			µs
t_{BUF}	Bus Free Time between a Stop and a Start Condition.		1.3			µs

SDA setup time: 100nS

SDA hold time: 20nS

BME280 I2C timing specification:

Table 33: I²C timings

Parameter	Symbol	Condition	Min	Typ	Max	Unit
SDI setup time	$t_{SU;DAT}$	S&F Mode HS mode	160 30			ns ns
SDI hold time	$t_{HD;DAT}$	S&F Mode, $C_b \le 100$ pF S&F Mode, $C_b \le 400$ pF HS mode, $C_b \le 100$ pF HS mode, $C_b \le 400$ pF	80 90 18 24		 115 150	ns ns ns ns
SCK low pulse	t_{LOW}	HS mode, $C_b \le 100$ pF V_{DDIO} = 1.62 V	160			ns
SCK low pulse	t_{LOW}	HS mode, $C_b \le 100$ pF V_{DDIO} = 1.2 V	210			ns

The above-mentioned I²C specific timings correspond to the following internal added delays:

- Input delay between SDI and SCK inputs: SDI is more delayed than SCK by typically 100 ns in Standard and Fast Modes and by typically 20 ns in High Speed Mode.
- Output delay from SCK falling edge to SDI output propagation is typically 140 ns in Standard and Fast Modes and typically 70 ns in High Speed Mode.

SDA setup time: 160nS

SDA hold time: 150nS

Worst case setup time:

I2C bus: Between the BME280 and the AS7331, the BME280 has a minimum setup time of 160nS.

SPI bus: Between the LCD and the ENS160, the LCD display will have minimum setup time of 227nS.

Worst case hold time:

I2C bus: Between the BME280 and the AS7331, the BME280 has a minimum hold time of 150nS.

SPI bus: Between the LCD and the ENS160, the LCD display will have minimum setup time of 525nS.

For applications involving high speed communication between devices, setup and hold time become critical. Furthermore, if the communication busses are being shared between different slaves, the worst-case timing specifications between all the slaves must be considered before choosing the clock speed.

Additionally, for applications involving dynamic weather conditions, these timings are further influenced by environmental factors.

High risk Development Items:

- Designing footprints for LGA (Land Grid Array) packages of components like the AS7331 and BME280 was challenging due to their compact size and intricate pin arrangements.
- Integrating the ENS160, which has an extremely high current consumption, into the circuit presents significant challenges.

Mitigation Plans:

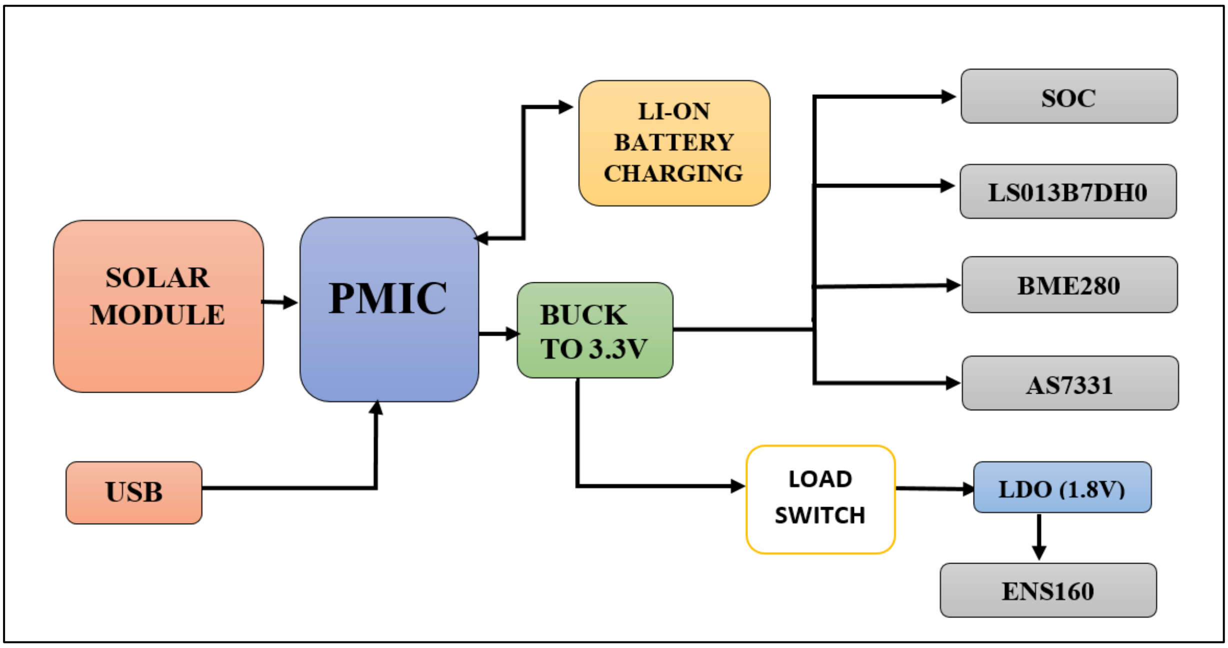
- For the high-risk development components mentioned above, footprints were meticulously designed with the assistance of SAs (Subject Matter Experts).
- The decision to incorporate a load switch into the circuit for the ENS160 was a strategic choice aimed at addressing challenges associated with its high current consumption and fluctuating power requirements.

Miscellaneous Updates:

- Updated Components:

COMPONENT	Important Features	Website Link	Datasheet & Digikey Part number
SOLAR CELL (Energy harvesting)	• VOC open circuit voltage 4.15 V • ISC short circuit current 58.6mA • Vmpp voltage at max. power point 3.35 V • Impp current at max. power point 55.1 mA	SM141K06L	DATASHEET SM141K06L-ND
LOAD-SWITCH	• Channel Select Input Over−Voltage Tolerant to 5.5 V • Fast Switching and Propagation Speeds	NLAST4599DFT2G	DATASHEET NLAST4599DFT2GOSCT-ND

- Updated Block Diagram:



- Updated Gannt chart link: Link

Project Week 4 Update

Status Report:

During this week, we began our circuitry design process, initially sketching out ideas and then progressing to implement the schematic using Altium. We have also updated our components list on GitHub.

Our upcoming activities include:

- Initiating work on the development kits.
- Completing the creation of the Component Library and Footprint Design.
- Conducting brainstorming sessions regarding component placement on the PCBs, taking into consideration our 3D printed module design.

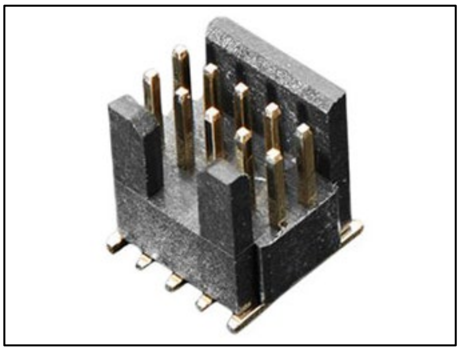
We have also updated the changes in the footprints and symbols after the review with Professors and SAs. Tasks have been created and updated on the GitHub Gantt Chart.

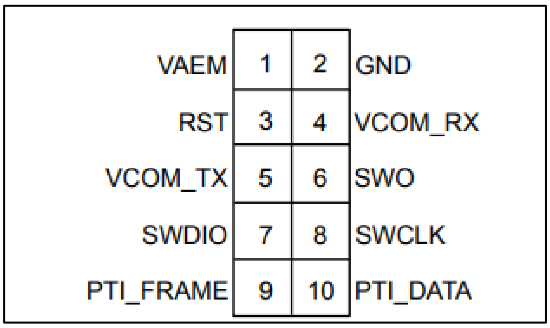
Analysis and Update requirements:

1. **What features, components, will need to be added to your schematic to enable programming of your micro controller or SoC?**

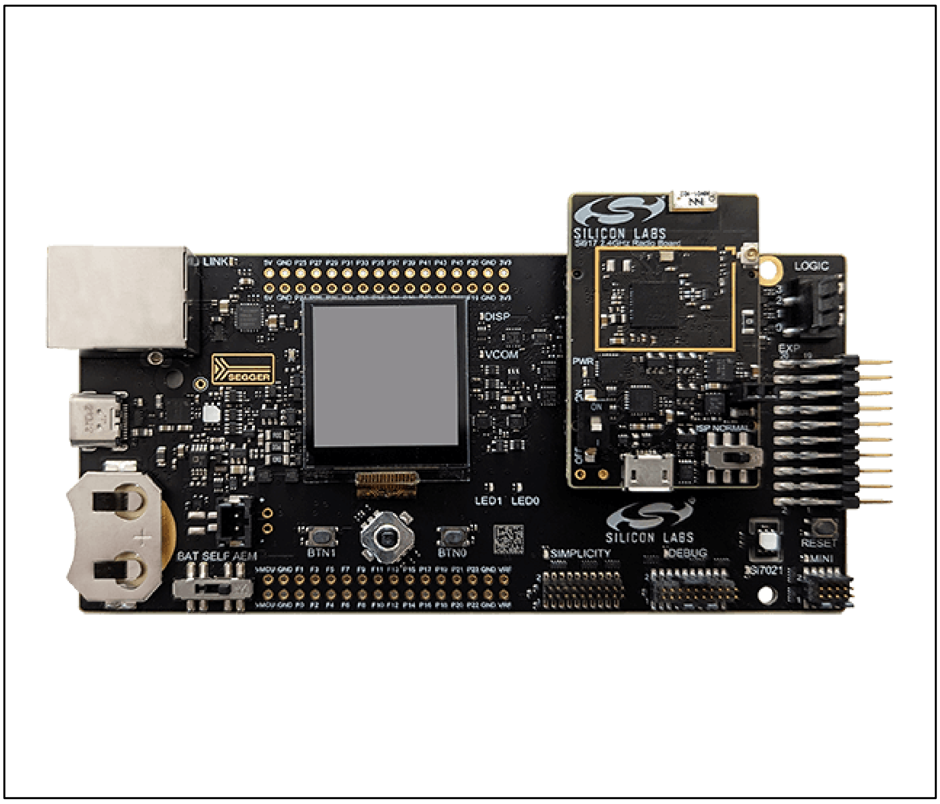
   There are three essential components to achieve flashing the efr32bg22 SoC on our custom board.

   a. Mini simplicity connector: The figure below shows the pin-out for this 10-pin Mini Simplicity connector. This connector is the interface between the SoC on our custom board and the programmer controller. This connector will be added onto our custom board, and we will use a ribbon cable to connect it to the dev kit, as mentioned below.

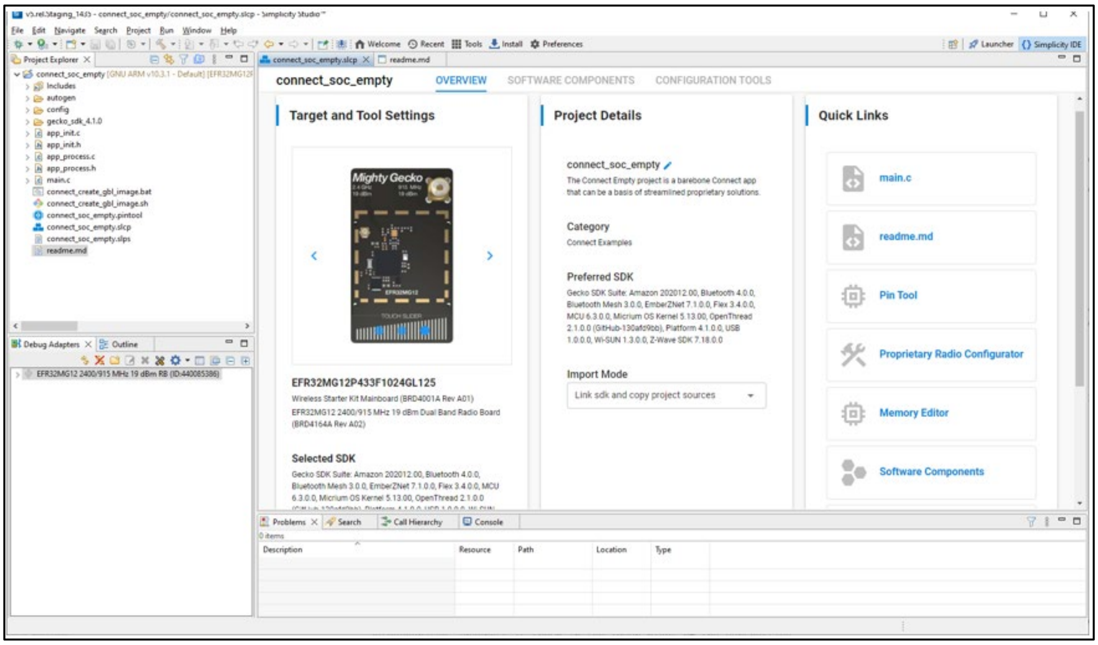




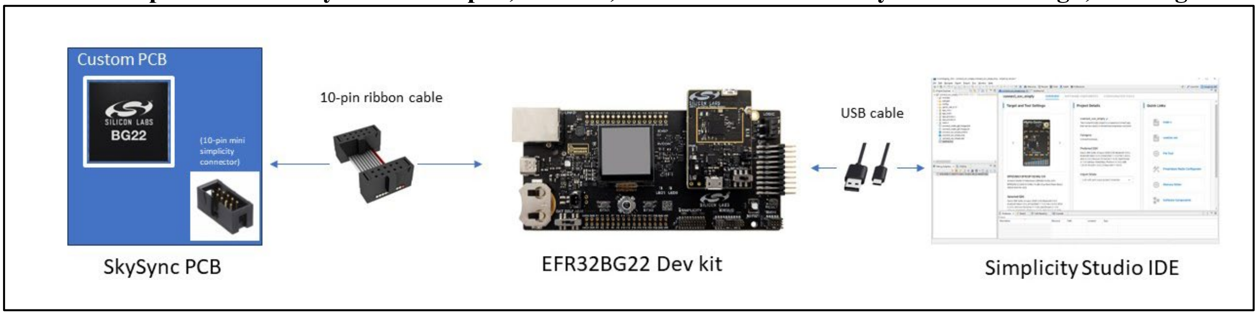
   b. A EFR32BG22 or similar dev kit: This development kit will enable us to connect our programming environment to our bare SoC. This board has a similar mini simplicity connector on-board as well.



c. Simplicity Studio: This IDE will enable us to develop our firmware as well as provide us with necessary interfacing drivers to connect to the EFR32BG22 dev board and eventually our target EFR32BG22 SoC.

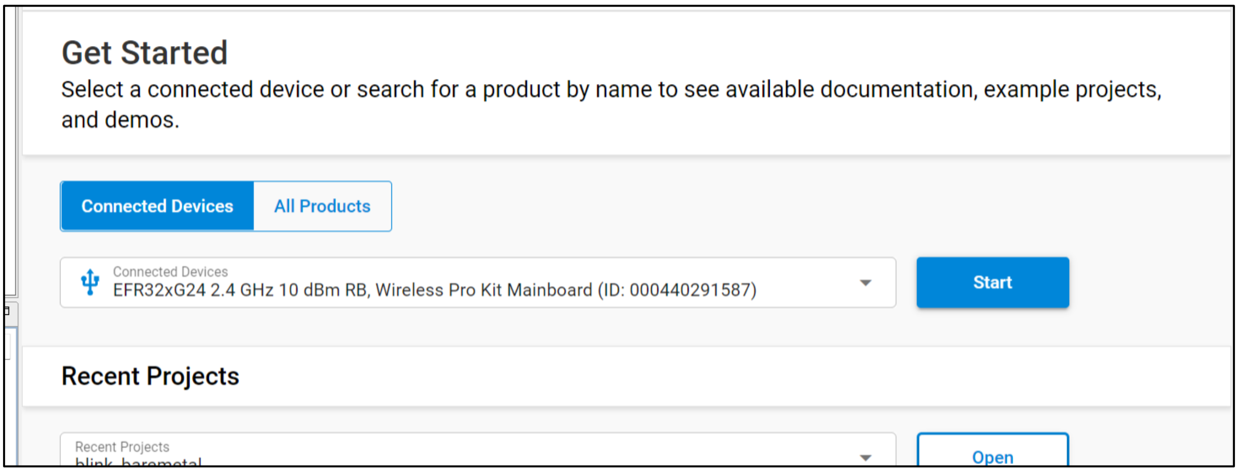


2. **Describe the process of how you will compile, connect, and download code to your board design, the target board**

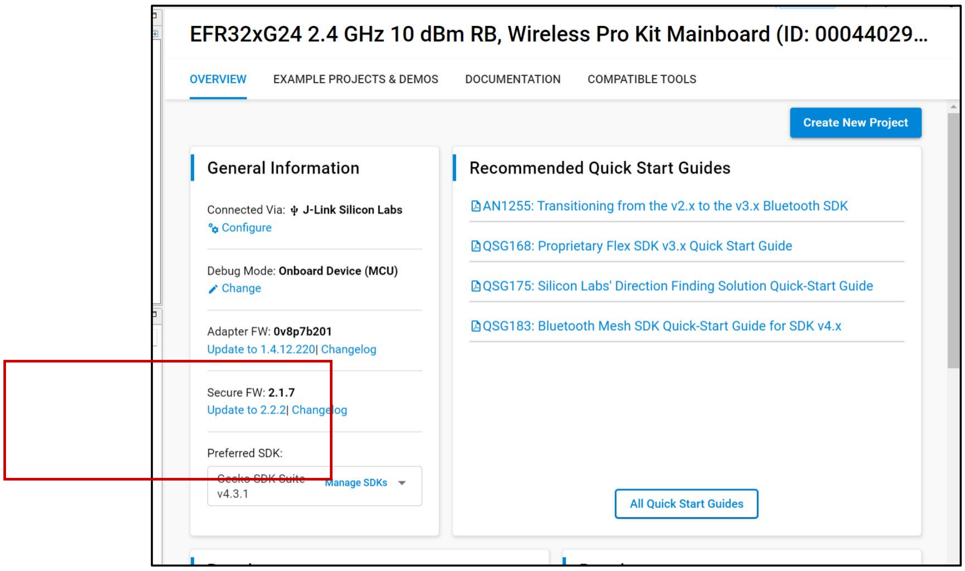


Steps:

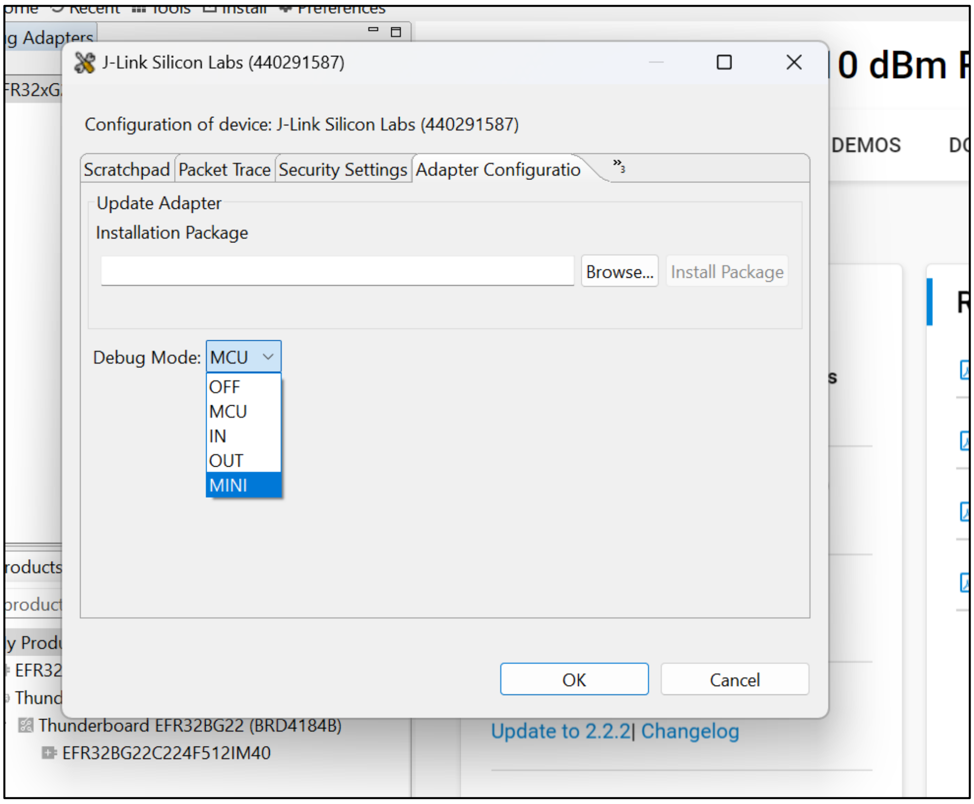
1. Connect the EFR32BG22 development kit to your computer via USB.
2. Ensure that the custom PCB with the EFR32BG22 SoC is properly powered, and the necessary connections (SWD, power, and ground) are made to the programmer interface on the custom board.
3. Connect the 10-pin mini connector from the custom board to the dev kit, as shown above.
4. Launch the development environment that comes with the development kit (Simplicity Studio) and connect the dev board to the computer.
5. The IDE detects the dev board and selects it. Click start.



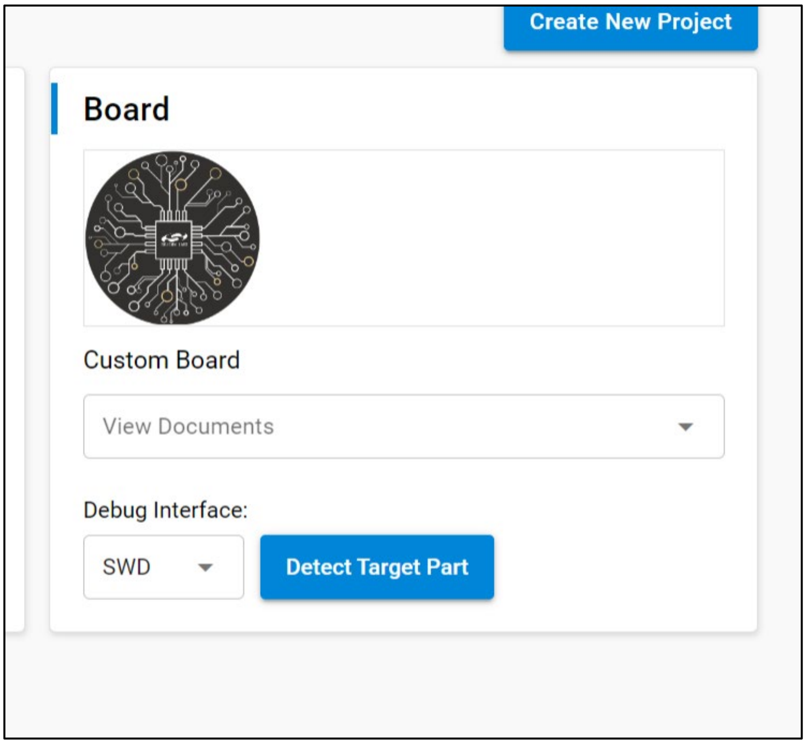
6. In the next window, change the debug mode from MCU to MINI



Clicking on change in above window should pop up the below window, allowing for changing debug mode from the on-board MCU of the dev kit to the SoC connected to the mini-interface.



7. The home page should look like this now. Select SWD from the drop down, if not already selected, and click detect part.



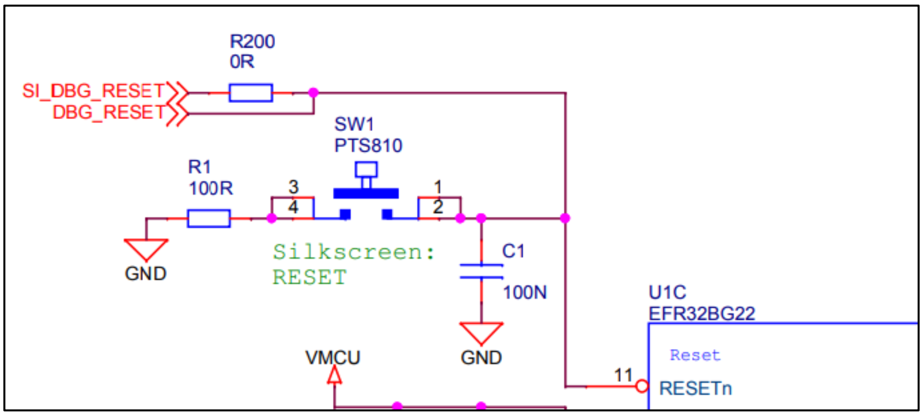
8. If the SoC is connected to the dev board via the mini connector, the IDE will detect it and load the necessary windows.

9. The IDE will now allow us to install the bootloader for the barebone SoC.
10. Now, the connection is established between the custom board's SoC and the IDE. The required firmware can be flashed using the Flash Programmer tool in the IDE.

3. Which signals will have test points?

- 3.3V Rail
- 1.8V Rail
- I2C
- SPI
- VBat
- Solar Panel
- PMIC VBAT OK
- PMIC VSTOR

4. Reset Circuit Description



Above is a brief schematic of the reset circuit for the EFR32BG22 series. EFR32 Wireless Gecko Series 2 processors are reset by driving the RESETn pin low. A weak internal pull-up device holds the RESETn pin high, allowing it to be left unconnected if no external reset source is required. Also connected to RESETn is a low-pass filter that prevents noise glitches from causing unintended resets. The internal pull-up ensures that the reset is released. When the device is not powered, RESETn must not be connected through an external pull-up to an active supply or otherwise driven high as this could damage the device.

The SI_DBG_RESET path allows the SoC to be reset through software for flashing and debugging purposes. The RST pinon the mini simplicity 10-pin connector is connected to the SI_DBG_RESET and allows the SoC to be reset through the Programming and Debugging Environment.

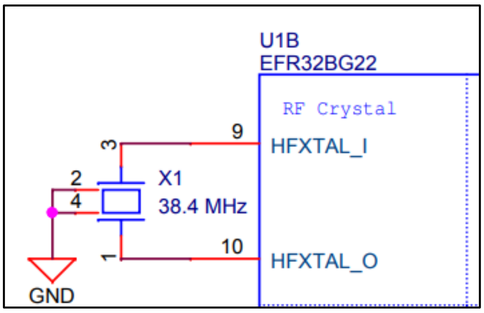
5. Clock Generation Description

EFM32 and EFR32 Wireless Gecko Series 2 devices support different external clock sources to provide the high- and low-frequency clocks in addition to the internal LF and HF RC oscillators. Possible external clock sources for both the LF and HF domains are crystals and external oscillators (square or sine wave)

- A high-frequency crystal oscillator (HFXO) with integrated load capacitors provides precise timing, particularly for RF applications. It can also support external clock sources like TCXOs for high accuracy.
- A 32.768 kHz crystal oscillator (LFXO) offers accuracy for low-power modes.
- An integrated high-frequency RC oscillator (HFRCO) is available when crystal precision isn't needed, with a wide frequency range.
- A fast start-up RC oscillator (FSRCO) runs at a fixed 20 MHz.

- A low-frequency 32.768 kHz RC oscillator (LFRCO) is suitable for low-power operation without an external crystal. It can be calibrated for improved accuracy.
- An ultra-low frequency 1 kHz RC oscillator (ULFRCO) provides timing with minimal energy consumption during low-power modes.

A crystal of 38-40 MHz is connected across the HFXTAL_I and HFXTAL_O pins on EFM32 and EFR32 Wireless Gecko Series 2 devices. External load capacitors are not required on EFM32 and EFR32 Wireless Gecko Series 2 devices. These have been moved on-chip and can be tuned by register bit fields under software control, thus reducing BOM cost and saving space in the PCB footprint.



Counters and timers in the EFR32BG22 perform various timing and counting functions:

- TIMER peripherals include 16-bit or 32-bit counters with up to 3 compare/capture channels. They support capture, compare, and PWM modes, allowing for diverse timing and PWM signal generation.
- The Low Energy Timer (LETIMER) is a 24-bit timer that operates even in low-energy modes, enabling simple tasks with minimal power consumption. It can output various waveforms.
- The Real-Time Clock with Capture (RTCC) is a 32-bit counter for timekeeping, working down to EM3 energy mode. It can be clocked by low-frequency oscillators and wake up the system at specified intervals.
- The Back-Up Real Time Counter (BURTC) is a 32-bit counter that operates in all energy modes, including EM4. It can also wake up the system at user-defined intervals.
- The Watchdog Timer (WDOG) can act as an independent watchdog or synchronize with the CPU clock. It monitors system failures and can generate resets or interrupts based on failure conditions. It can also monitor systems controlled by the Peripheral Reflex System (PRS).

In essence, the CMU manages clocks and oscillators, while various timers and counters perform timing, counting, and pulse-width modulation tasks, allowing the EFR32BG22 microcontroller to efficiently control and coordinate various functions in different energy modes.

6. Provide an alternative energy source other than the energy harvester.

Using USB as an alternative energy source provides a convenient and readily available way to power our module during development, testing, or situations where the primary energy harvester isn't functional. It will allow us to verify and debug the PMU circuitry before relying solely on harvested energy.

7. Jump Start method to charge the energy storage element if the Energy Harvester circuity is not functional or takes too long.

When we found out that PMIC takes too long to charge the battery (approximately 8 hrs.), so we thought of battery charging separate circuitry using MCP73812 battery charging IC. This is going to be our stretch goal. It reduces the time to 2 hrs for charging the IC. Additionally, we will be using USB.

8. What is the maximum charging current allowed by the PMU circuitry?

The charger has a typical cycle-by-cycle current limit of 230 mA and operates within an input voltage range of 0.5V to 4.0V, with a target storage voltage (VSTOR) of 4.2 V.

9. What is the maximum charging current allowed by the energy storage unit specs? What will the maximum current of the jump start power source be set to? Where will the jump start power and ground signals connect to?

Maximum Charge Current for our battery is 850 mA 1.0C.

The maximum current of the jump start power source should not exceed the maximum charging current allowed by the battery. In this case, since the battery's maximum charging current is 850 mA (1.0C), we can set the maximum current of the jump start power source to a value that is less than or equal to 850 mA to ensure safe and controlled charging of the battery.

For jump-starting via USB Type-C, the power and ground signals should connect to the corresponding pins on the USB Type-C connector. USB Type-C connectors typically have pins for VBUS (power) and GND (ground).

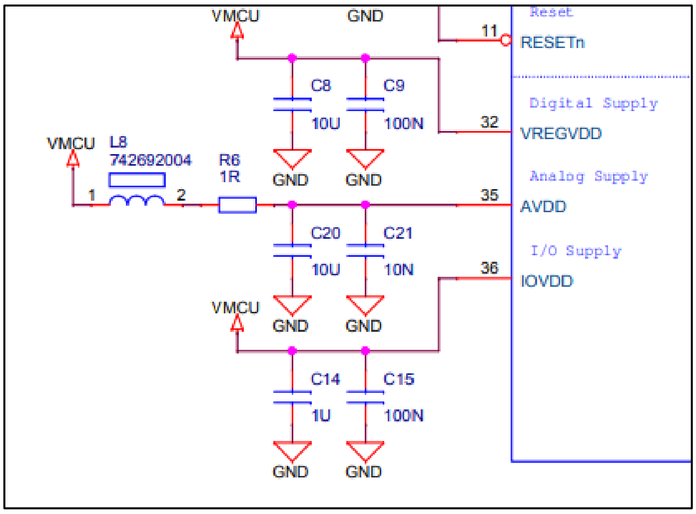
10. Ensuring that there is enough energy / current to program the flash of the MCU • How much current will the programming of the MCU flash require? • How much current will the energy storage element and the PMU be able to provide?

The EFR32BG22 has an onboard flash to store program code. During the programming of the MCU, the flash memory is erased and written multiple times. To erase a page of code space, up to 1.34 mA of current is required. During the programming of the flash, a maximum of 1.45 mA of current is required from the supply.

Program Current	I_{PROG}		—	—	1.45	mA
Page Erase Current	I_{PERASE}	Page Erase	—	—	1.34	mA

The choice of PMIC BQ25570 means that we can source up to 110mA of peak current. The battery can source up to 425 mA of peak current and is only bottlenecked by the PMIC which is 110 mA. This current is approx. 100x the current required to program the flash. Hence, the energy storage element and the PMU can support programming the flash memory easily.

• What are the connection points to enable external power to digital / MCU portion of the board



The EFR32BG22 has three different supply sections to power all of its internals. The analog, the digital and IO supply. The Digital supply, which also acts as the input to the internal Buck regulator, is connected to the main supply voltage. The input supply VREGVDD has a maximum range between 1.8 and 3.8 V but is limited by application parameters, including transient current load, operating junction temperature, and the lifetime average current load.
The output of the DCDC regulator is V_{dcdc} produces a nominal 1.8V. The DCDC output (VDCDC) is connected to DVDD, which

powers the internal digital LDO. Both radio power supplies (RFVDD and PAVDD) are also powered from the DCDC output.

V_{MCU} is the main supply voltage. C_{VDD} is the decoupling capacitor of about 10uF. These are the main two components required to power the digital portion of the MCU. This also powers the internal Buck regulator. The output of the buck regulator powers rest of the core board functionality.

Miscellaneous Updates:

- Integrated library was updated with additional components like alternative UV Index sensor Si1133, Solar Cell, Schottky Diode and JST Micro connectors. Components Link
- Additional battery capacity sensor was added as an additional goal after discussing with Prof Randy and SAs. VBAT will be measured at the ADC periodically to determine the battery capacity based on the Li-ion discharge curve.
- PMIC capacitor and resistor calculations completed and updated on: PMIC Calculations
- Updated Gannt chart link: Link

Project Week 5 Update

Status Report:

During this week, we had our schematic review.

- After receiving feedback from the professors and the TAs on our design, we incorporated those changes into our schematic.
- Additionally, we made changes of our own, which are mentioned at the end of the document.
- Post that, we decided our board design and number of daughter boards and split the components based on that.
- After one last round of symbol and footprint validation manually, we verified the entire schematic from top to bottom.
- After deciding the board sizes, we created PCBDoc in our project and placed all the components.
- After initial placement, we had a preliminary review with the TAs to validate our board shapes.

Upcoming activities:

- Placement review with the TAs.
- Software demo for talking with the sensors.
- Initial Routing by Thursday. First draft by end of Saturday.

Tasks have been added to GitHub to reflect the current and the next weeks tasks and allocations.

Analysis and Update requirements:

1. **Based on the PMU / Capacitance simulation assignment, what is the actual bulk capacitance required for each of your power planes/voltages?**

   Based on the PMU simulation of a LT8604 to match the characteristics of our circuit's BQ25570 at 500KHz switching frequency, the voltage droop during peak current consumption and voltage ripple during transient current were well below the thresholds of the EFR32BG22 SoC. There is no need for a bulk capacitor and our project would still function correctly. However, we would like to provide a set of solder points for a bulk capacitor and assemble them if required.

2. **To achieve this actual capacitance, what are the part numbers chosen and provide data that verifies the effective capacitance at voltage DC bias of your system.**

   As we are not going to use a bulk capacitor yet, the above question does not apply to us. Even without the use of a bulk capacitance, the SoC and other peripherals can handle voltage droops and ripples. As planned earlier, a bulk capacitance of 100uF would be ideal for our circuit without added extra rise time for signals.

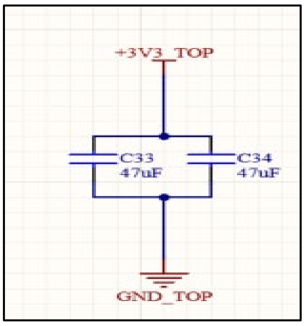


Figure 3 Bulk capacitors

A couple of 47uF capacitors have been added to achieve about 100uF of capacitance.

3. I/O ports in the design

Power connections:

Two Power supplies

a. USB - VBUS
b. Solar Panel – VSOL

Buttons:

Two pushbuttons

a. Reset- SW1
b. User interface button – SW2

Switches:

a. The ADC differential pin is also used as the Rx of the UART. To be able to use both the pins for their intended purposes, a three-way switch has been added (J6). Jumpers can be used to switch functionality between battery sensing and UART communications.
b. A switch has been provided at the input of the PMIC to turn off the power to it off completely.
c. Two indicator LEDs have been added, one for power and one for VBAT. Both LEDs can be turned off using switches.
d. The Battery capacity sensing switch consists of two GPIO controlled switches driven by the same GPIO. One of the switches enables the battery to directly discharge through a resistor divider network which generates the signal for analog sampling. The other switch can be configured to detach the charging sources feeding into the PMIC with a jumper.

I/O devices

a. ENS160: CO gas sensor over I2C
b. BME280: Temperature, Pressure and Humidity sensor over I2C
c. Si1133: UV index sensor over I2C
d. LS013B7DH03: low power 128x128 monochrome LCD display over SPI
e. Pushbutton: User Interfacing Pushbutton over GPIO
f. Solar Panel
g. NLAST4599DFT2G: Battery Capacity sensor
h. Mini Simplicity Connector: For programming and debugging.
i. USB C added with necessary resistors added to draw 5V.
j. LiPo battery
k. BQ25570 PMIC
l. Power LED, User LED and VBAT LED
m. Reset button.

4. ESD protection for these I/O ports.

There are two sources of high transient voltages in the circuit. USB C and mini simplicity connector. The mini simplicity connector on the Pro kit has ESD diodes. These diodes prevent voltage transitions on the programming and debug port. As we will only use the simplicity connector through the pro-development kit, it is wise to exclude extra ESD diodes in our board design, both to save space and cost.

The USB C port is another source of high voltage changes. For this, we have chosen the Littlefuse's SP1003 TVS diode. This ESD diode can absorb up to 30kV of surge and can safely dissipate up to 7A of current. With a low leakage current of 100nA and tiny package, it is viable to use these diodes on the Voltage bus of the USB C port. As our USB C port is not used for data transfer, there is no need for additional ESD diodes.

5. What is the p/n and why was it chosen?

The Littlefuse's SP1003 TVS diode provides adequate features to use at the voltage lines of the USB C port. No USB data lines were used so no ESD diodes were placed there. The reasoning behind selection of this diode is mentioned in the previous section.

Miscellaneous Updates:

I2C single bus update

A design change has been made to our circuit to allow simplification in design as well as placement of the sensors. The initial idea was to have two sensors on the I2C bus and one sensor and one display on the SPI bus. After careful considerations, we have decided to move all the sensors to the I2C bus to allow for the LCD to be completely occupying the single SPI bus. This reduces the need of CS on the GPIO of the SoC. This also helps in routing, as all sensors are grouped and placed close to each other on the board.

Two UV sensor update

As discussed with the professor in the class, we had a conflict in the choice of the UV sensor after a new UV index sensor became available and in stock close to the schematic submission. Hence, we decided to go forward with that new sensor. But due to logistical issues, the new sensor took time to be delivered and we ended up making symbols and footprints of both these sensors. As the AS7331 allowed for more features, but the Si1133 provided better documentation, we have decided to add both sensors on the board, on the same I2C bus. This allows us to use the backup (AS7331) if the primary one (Si1133) is not firmware ready in time. There will be a part missing on our main board if our silicon labs sensor passes our initial testing.

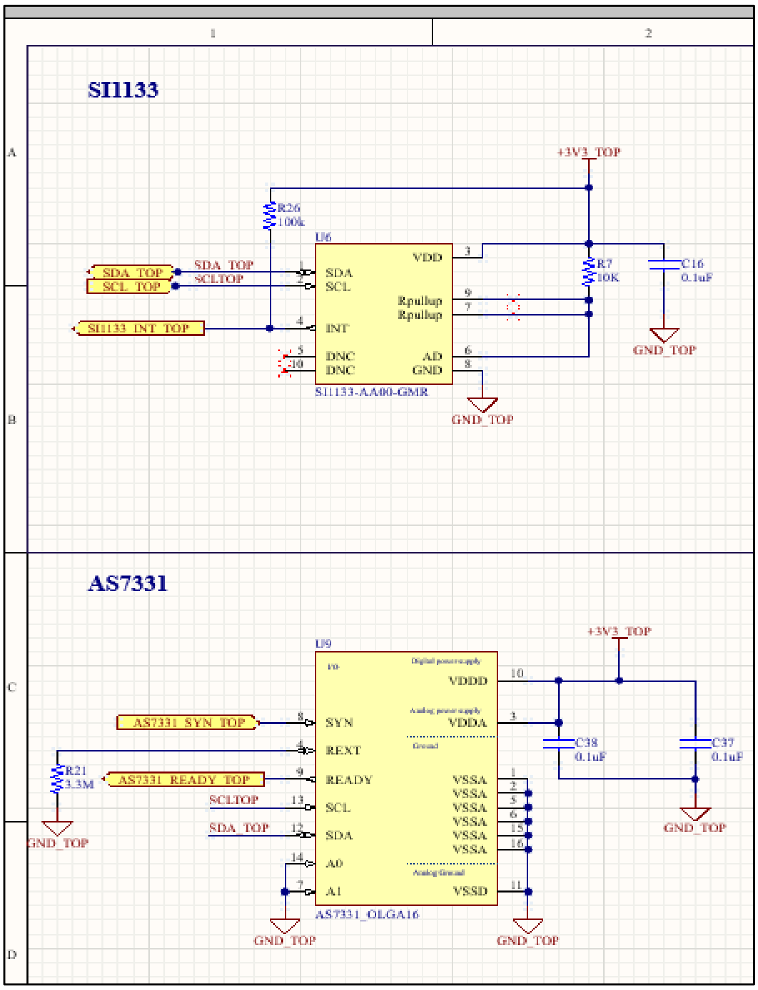


Figure 4 Multiple UV sensors on schematic

Board design update

To start with the placement of the components, we had to design the products mechanical design which would allow us to break down the components on to different board. For this, we have chosen to split the product into two halves/boards. The top board and the bottom board. Both boards will be mounted on to each other with their bottom layers facing each other. Below figure gives a visual representation of our design

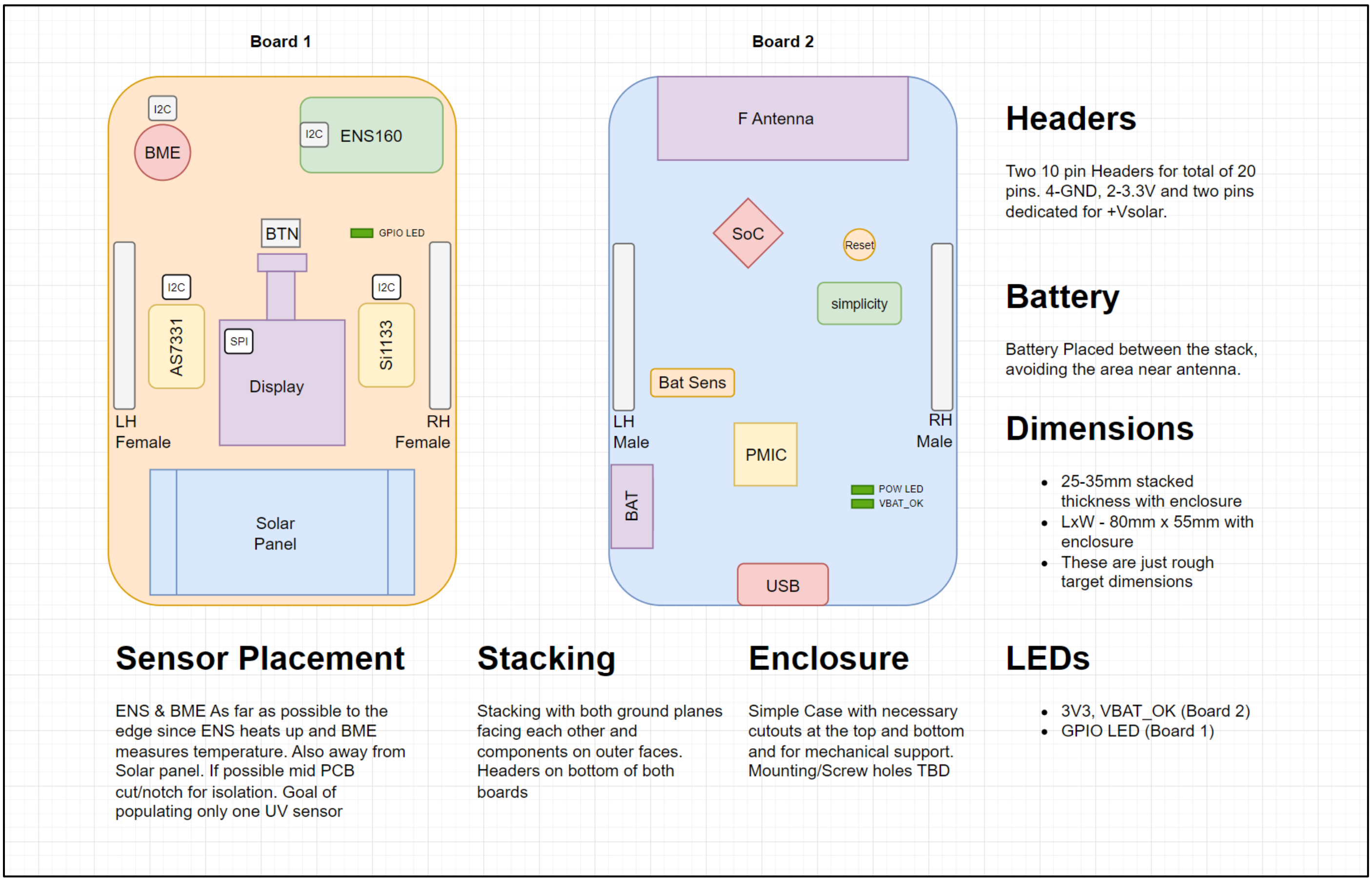


Figure 5 Product design and Board layouts

The headers on the top board will be placed on the bottom layers and will be female in nature. The headers placed on the bottom layers of the bottom board will be male in nature. These headers allow for power and data transmission between both of our boards. The LiPo battery will be placed in the gap between both the boards.

The top board will have the solar panel as well as the UV sensor as both components work on the same environmental factor. The top board is also the User interface board with the presence of a push button and a LCD display. The bottom board is more a backend board with the presence of reset button, debugger and programming port and the USB C charging port.

Project Week 6 Update

Status Report:

- With respect to the layout, we've made significant changes according to the feedback. Removed all the large cross unders and made the bottom board wider by about 10mils to route traces around the board.
- Now we are working on finishing more of the feedback items.
- Updated the header pin assignment to make routing better and also added GND header pin to make it easier to use with an Oscilloscope.
- Majority of the work left is fixing the top overlay, bottom overlay, and final verification of all the routes and board items.
- All the parts necessary were available on DigiKey and the parts were sent to order.
- We are having some issues trying to come up with optimal locations for mounting holes. Plus our progress on the firmware side has stalled for a bit and need to pick up the slack.
- Gantt chart updated -> https://github.com/users/neohere97/projects/1/views/7

Miscellaneous Updates:

- We received 5 samples of the AS7331 UV Sensor from the manufacturer.
- Simplified the Battery sensing circuitry by removing a second load switch needed to control PMIC input. This reduces the accuracy of measuring battery capacity, but we felt it was a good compromise considering the routing complexity it brings vs experimental nature of the sensor. We also moved from differential analog sampling to single ended. Now we're targeting to estimate the battery capacity in 25% range.
- The SP1003 package we had chosen was already the SOD723 package with the leads externally visible.

Project Week 7 Update

Status Report:

Last week the PCB orders were placed and are scheduled to arrive by early next week. We have also scheduled our ITLL slots to assemble our board. Here are some updates since our last project update.

- Layout underwent some changes in terms of placement to help reduce cross unders.
- Battery connector was placed on the bottom layer of the bottom board to reduce wire going around the boards.
- The battery sensing circuit was moved from a differential pair analog comparator to a single ended comparator to avoid long cross unders on the bottom board.
- Final routing review was done with the Professors and the SAs and the board order was placed after a successful DFM.
- Components were also ordered and are scheduled to arrive before the PCBs.
- After a discussion with the professors, the board colour was decided to be kept at green instead of going for black.
- Verification plan has been developed.
- Work has begun on writing the starter boot code to verify functionality of the boards blockwise.

Upcoming activities:

- Verification of the part order to be done after taking delivery of the Digi key parts.
- Labelling of SMD parts which do not have codes on them to be done before assembly.
- Taking sufficient printouts of board layers for the day of assembly.
- Board assembly and preliminary testing planned this week.
- Firmware development to begin after completing preliminary testing.

Tasks have been added to GitHub to reflect the current and the next weeks tasks and allocations.

Analysis and Update requirements:

We have uploaded our verification plan in excel sheet and uploaded it on GitHub.

- Verification Plan: Git Link

Miscellaneous Updates:

- We got to know that we haven't added thermal relief for the vias. So, we are looking into reflow profiles to set the appropriate temperature for the oven to fix the issue.

Project Week 8 Update

Status Report:

Two weeks ago, we assembled our PCBs in the ITLL lab, and since then, we have been verifying the boards according to the verification plan. Here are some updates since our last project update:

- We discovered that the load switch footprint did not match the component we ordered. Consequently, we have requested to reorder the correct part.
- The battery connector and ESD diode were hand-soldered on the bottom layer of the bottom board.
- Hardware tests were conducted on all three boards.
- The code was successfully uploaded, and Bluetooth was tested on all three boards.

Upcoming activities:

- Firmware development.

Tasks have been added to GitHub to reflect the current and the next weeks tasks and allocations.

Analysis and Update requirements:

We have uploaded our verification plan in excel sheet and uploaded it on GitHub.

- Verification Plan: Git Link

Miscellaneous Updates:

- We just found that the CS pin connection on the LCD is wrong (we have it grounded assuming it was active low). We are trying to figure out the ways to fix it.